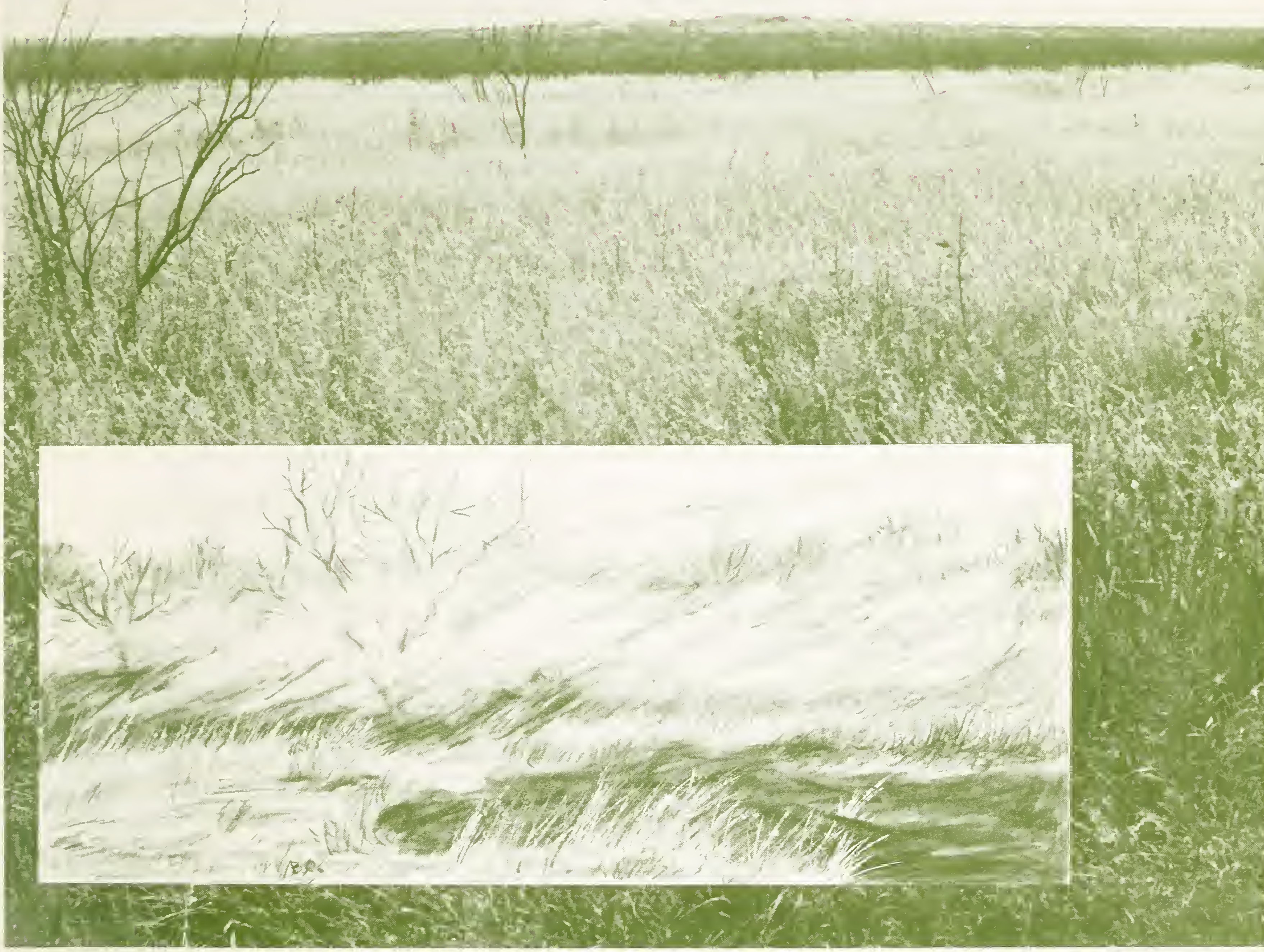

FIRE ECOLOGY AND PRESCRIBED BURNING IN THE GREAT PLAINS--A RESEARCH REVIEW

HENRY A. WRIGHT ARTHUR W. BAILEY

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RESEARCH SUMMARY

Historical evidence indicates that fires were prevalent in grasslands. In the past, big prairie fires usually occurred during drought years that followed 1 to 3 years of above-average precipitation, which provided abundant and continuous fuel. Fire frequency probably varied from 5 to 10 years in level-to-rolling topography and from 15 to 30 years in the rougher, dissected topography containing rough breaks and rivers.

This paper contains basic ecological information, vegetative descriptions, and fire effects data for the shortgrass, mixed grass, and tallgrass prairies in the southern, central, and northern Great Plains. In the appendix, fire effects data have been tabulated for each species for quick reference. Prescription guides are provided for all major vegetation types where prescribed burning data have been collected.

In the shortgrass prairie, grasses do not benefit from prescribed burning, but fire can be used to clean up uprooted brush, kill small juniper, and kill cactus. Prescribed fire has a wider variety of uses in the mixed and tallgrass prairies, particularly if the burns are conducted following winters with above-average precipitation. Major benefits of prescribed burning are to control undesirable shrubs and trees, burn dead debris, increase herbage yields, increase utilization of coarse grasses, increase availability of forage, improve wildlife habitat, and to control exotic, cool-season grasses. Often, several objectives can be achieved simultaneously.

Prescribed fire frequency should not be more often than 5 to 8 years in a 20-inch (51-cm) precipitation zone but can be as often as 1 to 3 years in a 35- to 40-inch (89- to 102-cm) precipitation zone. Good soil moisture in the upper 1 ft (0.3 m) of soil is especially important before conducting a prescribed burn if the goal is to increase yield and palatability of forage. If control of shrubs is the primary consideration, such as in juniper country, burning during drought years may have the best long-term effect.

To use prescribed fire is not as dangerous as most people think, providing it is done by experienced personnel. We recommed a minimum of 2 years of prescribed burning experience under a range of weather conditions for individuals having major supervisory responsibilities. Moreover, we recommend that supervisors be trained in planning and conducting burns and in evaluating the weather. To achieve a desired effect and for safety, one must have the skill to recognize, and the patience to wait for favorable weather.

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INTRODUCTION

The historical prevalence of fire in grasslands cannot be denied (Fidler 1793; Moss 1932; Sauer 1944; Stewart 1951, 1953; Dix 1960; Humphrey 1962; Jackson 1965; Nelson and England 1971; Kirsch and Kruse 1972; Seevers and others 1973). For example, the diary of Fidler (1793), who observed fires in the fescue grassland of southwestern Alberta, contains these statements:

> "These large plains either in one place or another is constantly on fire and when the grass happens to be long and the wind high, the sight is grand and awful, and it drives along with amazing swiftness. The lightning in the spring and fall frequently lights the grass, and in winter it is done by the Indians." And later, "These fires among the long grass is very dangerous."

Although lightning caused many fires (Haley 1929; Komarek 1966) and the Indians set some (Nelson and England 1971; Heady 1972), most documented conflagrations of the shortgrass prairie in the late 1880's were the result of carelessness by trail outfits, cowboys, and cooks (Haley 1929). Today, dry lightning storms and man are the major causes of fire in grasslands. Regardless of origin, fires have always been common and widespread on prairies during drought years.

In the semi-arid areas, big prairie fires in the past usually occurred during drought years that followed 1 to 3 years of above-average precipitation, which provided abundant and continuous fuel. Consequently, wildfires traveled for many miles (km) when the winds and air temperatures were high and relative humidity was low. An example is an account of a fire (Haley 1929) that started in the fall of 1885 in the Arkansas River country of western Kansas. It jumped the Cimarron River, burned across the North Plains of Texas, and did not stop until it reached the rugged Canadian River Breaks, a distance of 175 miles (282 km). A million acres (404 854 ha) of the XIT Ranch alone burned in Texas. Haley (1929) gave several other accounts of large fires [20 by 60 miles (32 by 97 km)] on the High Plains of Texas.

Many grassland fires still start during dry weather, but they do not travel as far as in the past. Cultivated land breaks up the continuous grass cover of the prairie. One of the largest fires observed by the senior author in the Texas-New Mexico area was started by a broken powerline in Lea County, N.M., in April 1974. Wind was 55 miles (89 km)/h, relative humidity was 5 percent, and air temperature was 100°F (38°C). Herbaceous growth from the previous year was abundant. The fire traveled 26 miles (42 km), burning 52 sections (13 474 ha), and crossed three major highways. It was finally stopped by a plowed field. This typifies the prairie fires of today and the conditions under which they will travel long distances.

FIRE HISTORY OF THE PRAIRIE GRASSLANDS

There are no reliable historical records of fire frequencies in prairie grassland because there are no trees to carry fire scars from which to estimate fire frequency. However, we know that fire frequency was high because explorers and settlers were concerned about the danger of prairie fires. We can extrapolate fire frequency data for grasslands from forests having grassland understories such as ponderosa pine (*Pinus ponderosa*) in the West and longleaf pine (*Pinus palustris*) in the Southeast. A variety of sources (Chapman 1926, 1944; Weaver 1951; Wagener 1961; Hall 1976; Arno 1976) indicate that fire frequency in pine forests varied from 2 to 25 years. Because prairie grassland is typically of level-to-rolling topography, a natural fire frequency of 5 to 10 years seems reasonable. In topography dissected with breaks and rivers, such as the Rolling Plains and Edwards Plateau of Texas, fire frequency may have been 20 to 30 years. The latter assumption is based on historical accounts by Marcy (1849) of large honey mesquite (*Prosopis glandulosa* var. *glandulosa*) trees in the Rolling Plains, and the frequency of fire that we know is necessary to keep large Ashe juniper trees (*Juniperus ashei*) out of prairies in the Edwards Plateau (Wink and Wright 1973).

How important have fires been in maintaining grasslands? Stewart (1951, 1953) and Sauer (1944) proposed that treeless grasslands are a product of repeated fires set by aborigines. Wedel (1957) and Hastings and Turner (1966) make a strong case for climate being the primary influence on American grasslands. Winter rainfall decreases rapidly from the Southeast to the center of the United States. Snowfall decreases rapidly from the eastern edge of the Rockies to the Southwest and across the northern margin of the Great Plains, making this area unsuitable for tree growth (Wedel 1957). Wells (1970) presented evidence that the origin and maintenance of grasslands is directly related to topography. He stated that the "rougher and more dissected the topography, the greater the former extent and the current spread of woody vegetation at the expense of grasslands."

Although we feel that climate is the dominant factor controlling North American grasslands, wide fluctuations in woody vegetation would occur if it was the *only* factor (Albertson and Weaver 1945; Bragg and Hulbert 1976). The impact of drought on the maintenance of grasslands has been illustrated by Albertson and Weaver (1945). They surveyed the mortality of natural trees, timber belts, old shelterbelts, and hedgerows following the drought of the 1930's. Their studies ranged from Oklahoma to Nebraska, and they recorded mortality rates ranging from 30 to 93 percent among the native deciduous trees [elm (*Ulmus* sp.), ash (*Fraxinus* sp.), hackberry (*Celtis occidentalis*)], and from 35 to 80 percent or higher among juniper.

On the eastern edge of the Great Plains "the balance between forest and grassland is so delicate that a little higher water content of soil, a slightly greater humidity, or protection from drying winds throws this balance in favor of tree growth, while the reverse conditions exclude it" (Albertson and Weaver 1945). Thus, there is good reason to believe that climate is the major factor in maintaining grasslands.

On level-to-undulating topography in the southern mixed prairie, drought (not necessarily severe), fire, insects, rodents, and competition from grass apparently interact to maintain grasslands. For example, in 1969 we burned mesquite trees that had been top-killed by herbicide in 1966. Of the 1,200 trees marked, 26 percent of them were killed over a 5-year period (Wright and others 1976a). Part of the mortality may be attributed to fire, but more than half of it seems to have resulted from the interaction of fire, a mild drought in 1970 and a severe one in 1971, insects, rodents, and competition from grass. A natural fire every 15 to 30 years in the southern mixed prairie could significantly reduce shrubs.

Shrubs and trees have always existed as scattered individuals or mottes on grasslands and along drainageways. In the Great Plains they are most abundant in the southern mixed prairie, mesic edge of the northern mixed prairie, eastern edge of the tallgrass prairie, and throughout the fescue prairie. Shrubs and trees are also present on rocky breaks or heavily grazed areas where fires are least frequent. Droughts can control shrub abundance where grass is healthy, but shifts from grasslands to shrubs and trees could occur on a 100-year cycle if vegetation was controlled solely by climate. Fire seems to have restricted shrub and tree growth in the past (Malin 1953), not so much as a single influence but in concert with other factors.

The restriction of shrub and tree growth by droughts, fire, and biotic factors did not eliminate trees in the southern mixed prairie nor on the eastern edge of the tallgrass prairie (Malin 1953). Open groves of large honey mesquite trees existed in the Rolling Plains of central Texas in 1849 (Marcy 1849). Historical evidence documents that these areas were subjected to fire (Michler 1850). Based on our experience, large honey mesquite and interior live oak (*Quercus virginiana*) trees are very tolerant of hot fires (crowns of trees remain alive), whereas trees less than 10 to 12 ft (3 to 4 m) tall can easily be top-killed. Thus, before the arrival of European man, one can easily surmise that it was feasible for a prairie fire to leave a mosaic of large trees, which left the appearance of a savanah, in the southern mixed prairie and the eastern tall grass prairie. Trees that were top-killed probably had a broad genetic base, as we will show in a later section, which permitted reburns to kill some trees and only suppress the resprouts of others.

Nonsprouting species such as Ashe juniper were more susceptible to fire. Wink and Wright (1973) have shown that hot fires could easily kill large juniper trees because of the volatility of the green material. Subsequent fires within 10 or 15 years could have killed the new juniper trees before they were old enough to produce seed, eliminating the potential local seed source of such a non-sprouting species. Thus, with occasional fires, such areas could easily have been converted to grasslands, with occasional patches of juniper on rocky sites. Protection from fire has favored the re-establishment of dense stands of juniper.

ECOLOGICAL CHARACTERISTICS AND EFFECTS OF FIRE

The vast North American Grassland lies between the Rocky Mountains and the eastern forest and extends from south-central Texas to the aspen-parkland in central Alberta and Saskatchewan (fig. 1). The grassland may be divided from west to east into the shortgrass, mixed, and tallgrass prairies, and grassland-forest combinations (Launchbaugh 1972). Because there is such a wide variation in species' combinations across the Great Plains, we will separate the area into the southern Great Plains, central Great Plains, and northern Great Plains. The northern Great Plains will include the aspen-parkland, a transitional zone of vegetation between the Great Plains grasslands and the Boreal Forest.

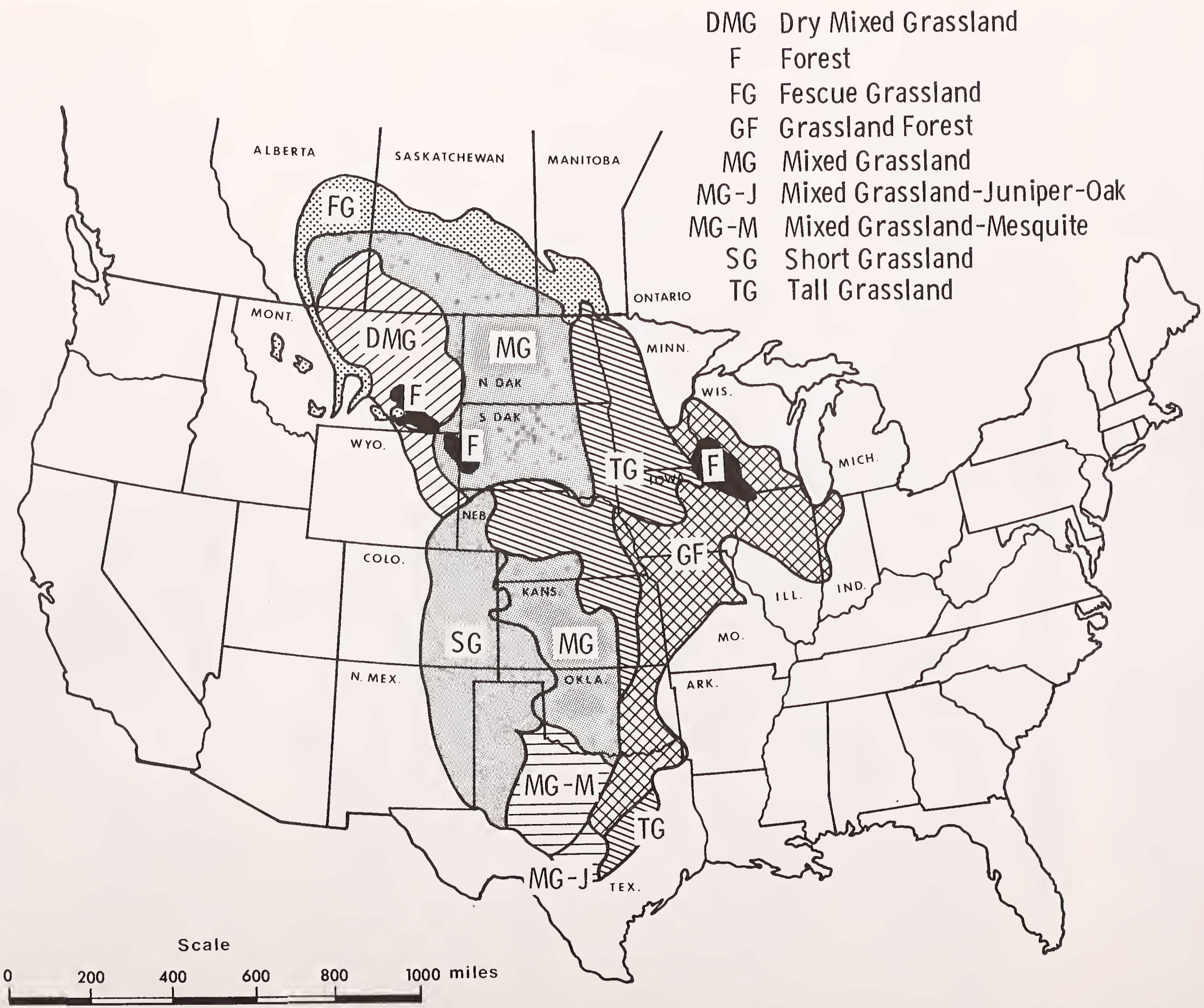

Figure 1.--Natural vegetation of Great Plains grasslands. Modified from Kuchler (1965) and Rowe (1972).

Southern Great Plains

DISTRIBUTION, CLIMATE, SOILS AND VEGETATION

The southern Great Plains includes the eastern third of New Mexico, the northern two-thirds of Texas, and most of Oklahoma. Within the region, the shortgrass prairie (High Plains) (fig. 2), lies west of the 100° meridian. Annual precipitation in the shortgrass prairie varies from 15 to 20 inches (38 to 51 cm). Except for the sandy soils in southeastern New Mexico and the Canadian River country in northern Texas and western Oklahoma, soils are primarily clay loams, silt loams, and sandy loams. A caliche layer is frequently present at 20 to 36 inches (51 to 91 cm) in the fine-textured soils. Most of the area is tableland that is 4,000 to 6,000 ft (1 200 to 1 829 m) elevation (south to north) on the western edge, and slopes eastward to 3,000 ft (915 m) on the edge of the Caprock in Texas. Dominant grasses are buffalograss (*Buchloe dactyloides*) and bluegrama (*Bouteloua gracilis*), with varying amounts of threeawns (*Aristida* sp), lovegrass (*Eragrostis* sp.), tridens (*Tridens* sp.), sand dropseed (*Sporobolus cryptandrus*), sideoats grama (*Bouteloua curtipendula*), tobosagrass (*Hilaria mutica*), galleta (*H. jamesii*), vine-mesquite (*Panicum obtusum*), bush muhly (*Muhlenbergia porteri*), and Arizona cottontop (*Digitaria californica*). Forbs can be abundant during wet years, but they are seldom a major component of the shortgrass prairie.

Figure 2.--Shortgrass prairie in Panhandle of northern Texas. Dominant species are blue grama and buffalograss.

Major forbs include annual broomweed (*Xanthocephalum dracunculoides*), false mesquite (*Hoffmanseggia densiflora*), western ragweed (*Ambrosia psilostachya*), horsetail conyza (*Conyza candensis*), warty euphorbia (*Euphorbia spathulata*), silverleaf nightshade (*Solanum elaeagnifolium*), manystem evax (*Evax multicaulis*), woolly plantago (*Plantago purshii*), dozedaisy (*Aphanostephus* sp.), goosefoot (*Chenopodium* sp.), croton (*Croton* sp.), summercypress (*Kochia scoparia*), and globemallow (*Sphaeralcea* sp.).

Dominant woody plants are honey mesquite, sand shinnery oak (*Quercus havardii*), sand sagebrush (*Artemisia filifolia*), perennial broomweed (*Xanthocephalum sarothrae*), yucca (*Yucca* sp.), and fourwing saltbush (*Atriplex canescens*). Cactus (*Opuntia* sp.) can also be abundant. The most prevalent species include plains pricklypear (*Opuntia polyacantha*), brownspine pricklypear (*O. phaecantha*), walkingstick cholla (*O. imbricata*), and tasajillo (*O. leptocaulis*).

East of the shortgrass plains is the mixed prairie (Rolling Plains and Edwards Plateau). It includes most of west-central Texas and western Oklahoma. Elevation drops from 3,000 ft (915 m) along the western edge to about 900 ft (274 m) along the eastern edge in central Texas and Oklahoma. Topography is undulating, with occasional breaks and rivers. The zone is about 150 miles (242 km) wide and precipitation varies from 20 inches (51 cm) on the western edge to 28 inches (71 cm) on the eastern edge. Soil textures are primarily clay loams, silt loams, and sandy loams.

Honey mesquite (fig. 3) and Ashe juniper (fig. 4) dominate the overstory in Texas, but these species are not prevalent in Oklahoma. In the Rolling Plains, honey mesquite dominates the overstory. Lotebush (*Zizyphus obtusifolia*) is an important subdominant shrub that provides cover for bobwhite quail and nesting for many songbirds (Renwald 1977; Renwald and others 1978). Other shrubs include fourwing saltbush, elbowbush (*Foresteria pubescens*), ephedra (*Ephedra* sp.), skunkbush sumac (*Rhus trilobata*), dalea (*Dalea* sp.), and acacia (*Acacia* sp.). Breaks throughout the Rolling Plains contain large amounts of redberry juniper (*Juniperus pinchoti*), which resprouts from crown buds after fire. Cactus species similar to those in the shortgrass prairie are also present throughout the Rolling Plains (fig. 5 and 6).

Dominant grasses include sideoats grama, tobosagrass, buffalograss, little bluestem (*Schizachyrium scoparium*), and the cool season grass, Texas wintergrass (*Stipa leucotricha*). Other grasses include vine-mesquite, Arizona cottontop, sand dropseed, white tridens (*Tridens albescens*), threeawn species, plains bristlegrass (*Setaria leucopila*), and green sprangletop (*Leptochloa dubia*). Many annual forbs grow during wet winters, but annual broomweed and bitterweed (*Hymenoxys odorata*) are the only forbs abundant over a wide area. Other genera include *Engelmannia, Gaillardia, Oenothera, Aphanostephus, Chenopodium, Gaura, Helianthus, Plantago, Solanum,* and *Sphaeralcea*.

In the Edwards Plateau, southeast of the Rolling Plains, Ashe juniper dominates the overstory. Other major species include interior live oak, Texas oak (*Quercus shumardii* var. *texana*), post oak (*Q. stellata*), blackjack oak (*Q. marilandica*), smoothleaf sumac (*Rhus glabra*), Mexican redbud (*Cercis canadensis* var. *mexicana*), and shin oak (*Quercus* sp.). Dominant grasses include little bluestem, sideoats grama, Texas wintergrass, tall grama (*Bouteloua pectinata*), vine-mesquite, buffalograss, and meadow dropseed (*Sporobolus asper* var. *hookeri*). Forbs are similar to those in the Rolling Plains.

Figure 3.--A mesquite-tobosa community (dormant season) with 4,070 lb/acre (4,573 kg/ha) of fine fuel in the mixed prairie near Colorado City, Texas.

Figure 4.--A heavily grazed stand of Ashe juniper in the mixed prairie of central Texas that will need a major reclamation program to revert it back to a natural grassland. Such communities need fire every 20 years or so and good management to keep Ashe juniper out.

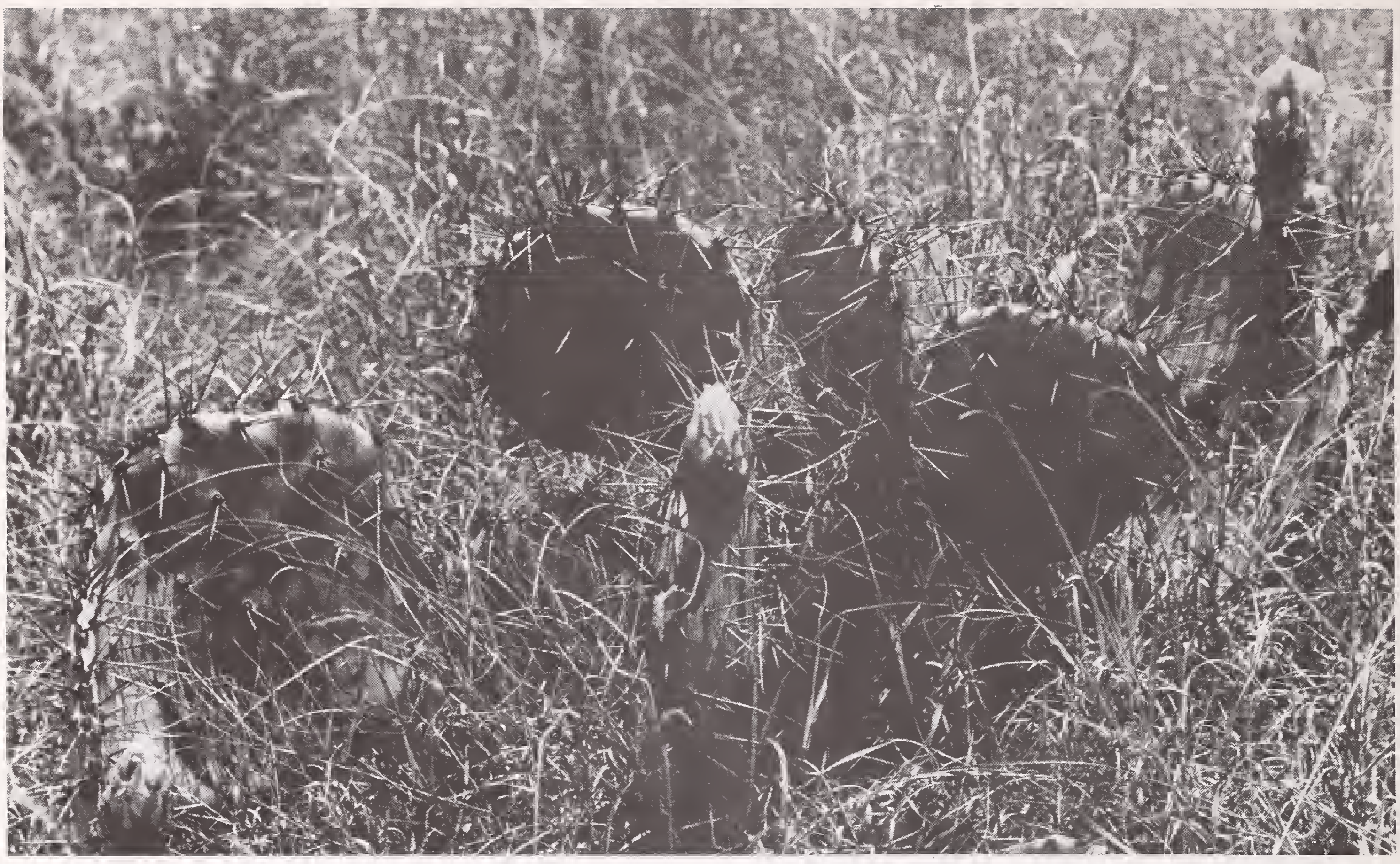

Figure 5.--Pricklypear (*Opuntia phaecantha*) can easily be killed with fire. Generally 70 to 80 percent of the plants are dead 2 to 3 years after a fire because of a fire-insect interaction.

Figure 6.--Cholla are easily killed if less than 2 ft (0.61 m) tall. About 50 percent of the plants die after being burned.

The tallgrass prairie is mixed with various amounts of the "Cross Timbers" from central Texas and Oklahoma to their eastern boundaries. The Cross Timbers are dominated by post oak and blackjack oak and occur on sandy soil. Precipitation varies from 27 to 45 inches (69 to 114 cm). Deep sandy loam and silt loam soils are common in the pure grasslands. Elevation varies from 500 to 1,000 ft (152 to 305 m), sloping generally to the east. Dominant grasses are little bluestem, big bluestem (*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*). Shrubs vary in abundance, with the important ones being smoothleaf sumac, leadplant (*Amorpha canescens*), and wild plum (*Prunus* sp.). Forbs are similar to those mentioned for tallgrass prairie of the central Great Plains.

FIRE EFFECTS - SHORTGRASS PRAIRIE

Grasses.--During dry years, most species of the shortgrass prairie are harmed by fire. Following a spring wildfire, when the soil was dry, Launchbaugh (1964) found that the recovery time for a buffalograss-blue grama community took three growing seasons. Recovery was 35, 62, and 97 percent following the first, second, and third growing seasons, respectively. Hopkins and others (1948) reported similar results in west-central Kansas. Western wheatgrass (*Agropyron smithii*) recovered more slowly--18, 27, 77 percent for the three growing seasons (Launchbaugh 1964). Following a wildfire in New Mexico when the moisture balance was more favorable, Dwyer and Pieper (1967) found that the production of blue grama was reduced only 30 percent the first year. With above-average precipitation the second year after burning, blue grama had recovered. Results from prescribed burns in Texas during years with above-normal winter and spring precipitation show that buffalograss and blue grama tolerate fire with no loss in herbage yield at the end of the first growing season (Trlica and Schuster 1969; Heirman and Wright 1973; Wright 1974b) (table 1).

Table 1.--*Yields of buffalograss and blue grama after burning during a year with above-normal precipitation (wet year) and a year with below-normal precipitation (dry year)*

Year after burn	Burned: Current growth	Burned: Litter	Unburned: Current growth	Unburned: Litter
	lb/ha (kg/acre)			
Wet years (Texas data)[1]				
Buffalograss				
First (1968)	1,686 (1,894)	-- --	1,494 (1,679)	728 (818)
Second (1969)	2,063 (2,318)	306 (344)	1,928 (2,166)	458 (515)
Third (1970)	1,398 (1,571)	572 (1,766)	1,330 (1,494)	906 (1,018)
Blue grama				
First (1970)	1,680 (1,888)	-- --	1,429 (1,606)	2,474 (2,780)
Second (1971)	1,369 (1,538)	699 (785)	1,247 (1,401)	2,584 (2,904)
Third (1972)	2,142 (2,407)	1,750 (1,966)	1,754 (1,971)	1,932 (2,171)
Dry years (Kansas data)[2]				
Buffalograss-blue grama				
First (1959)	1,100 (1,236)	-- --	3,150 (3,539)	500 (562)
Second (1960)	1,840 (2,067)	250 (281)	3,000 (3,371)	500 (562)
Third (1961)	2,600 (2,921)	330 (371)	2,650 (2,978)	550 (618)

[1]Data from Wright (1974b).
[2]Data from Lauchbaugh (1964).

The tolerance of most grass species to fire in the shortgrass prairie, under different moisture regimes, appears to be similar to that for buffalograss and blue grama. Red threeawn (*Aristida longiseta*) and sand dropseed are usually harmed by fire (Hopkins and others 1948; Dwyer and Pieper 1967; Trlica and Schuster 1969). By contrast, Wright (1974b) found that sand dropseed tolerated fire when winter and spring precipitation were 40 percent above normal. Other species that Dwyer and Pieper (1967) found to be harmed by fire included slim-stemmed muhly (*Muhlenbergia filiculmis*), ring muhly (*M. torreyi*), wolftail (*Lycurus phleoides*), and galleta. These species were harmed by a wildfire during a year of below normal precipitation. Tumble windmillgrass (*Schedonnardus paniculatus*) was not harmed by fire (Trlica and Schuster 1969). Weeping lovegrass (*Eragrostis curvula*), an introduced species, is increased 14 percent by burning, but the greatest benefit from burning is a 53 percent increase in utilization (Klett and others 1971).

In the southern shortgrass plains, sandy lands are common among the heavy clay soils that are dominated by buffalograss and blue grama. The sandy soils are dominated by sand bluestem (*Andropogon hallii*), little bluestem, switchgrass, and sand shinnery oak. Burning generally increases production of sand bluestem and switchgrass about 300 lb/acre (337 kg/ha) and similarly decreases production of little bluestem, with a net increase in total forage of 20 percent (McIlvain and Armstrong 1968).

Forbs.--Grasses provide the major portion of prairie vegetation, but many species of forbs occur during years with above-normal precipitation. Heirman and Wright (1973) found that spring burning was temporarily detrimental to many forbs: annual broomweed, silverleaf nightshade, western ragweed, and horsetail conyza. Warty euphorbia, multistem evax, and woolly plantago were not affected, and false mesquite was favored by the burn.

Total forb yields are usually reduced more by spring burns than fall burns (Hopkins and others 1948). In all cases, however, forb composition will be altered the least by burning when plants are dormant. Young, active growing forbs will be severely harmed by fire.

Shrubs.--The shortgrass prairie does not have many species of shrubs, but shrubby mesquite is abundant on native ranges in the southern mixed prairie. Mesquite has not always been a noticeably prevalent shrub on the High Plains (shortgrass prairie) of Texas. The following observations were made by Captain R. B. Marcy (1849) as he traveled with his command over the northern part of the Llano Estacado near present day Amarillo, Texas:

> When we were on the high tableland, a view presented itself as boundless as the ocean. Not a tree, shrub, or any other object, either animate or inanimate, relieved the dreary monotony of the prospect; it was a vast illimitable expanse of desert prairie--the dreaded "Llano Estacado" of New Mexico; or, in otherwords, the great Zahara of North America. It is a region almost as vast and trackless as the ocean--a land where no man, either savage or civilized permanently abides; it spreads forth into a treeless, desolate waster of uninhabited solitude, which always has been, and must continue, uninhabited forever; even the savages dare not venture to cross it except at two or three places, where they know water can be found. The only herbage upon these barren plains is a very short buffalograss, and, on account of a scarcity of water, all animals appear to shun it.

Today, honey mesquite is not only prevalent on the High Plains, but it is almost impossible to kill with fire after it is 1 ft (0.3 m) tall (Wright and others 1976a). Even the seedlings are very tolerant of fire (Fisher 1947). Honey mesquite on the High Plains has an exceptional ability to resprout, compared to mesquite in the Rolling Plains (mixed prairie). Based on fire tolerance and the very few recorded observations of honey mesquite by early explorers on the High Plains (Malin 1953; Box 1967), we believe that before European man's arrival honey mesquite maintained a low growth form and high frequency. On the High Plains, honey mesquite seems to be genetically adapted to fire because of the necessity to survive frequent fires in its past history. Thus, it is possible that the combination of fire, drought, competition from grasses, and damage from small mammals, particularly rabbits and rats, combined to maintain a low-growth form of mesquite.

On sandy loams in eastern New Mexico, northern Texas, and western Oklahoma, sand shinnery oak is abundant, while in southeastern New Mexico the sandy land is dominated by shrubby honey mesquite. Sand shinnery oak is fire tolerant. Density of its stems increases 15 percent after burning (McIlvain and Armstrong 1966); however, acorns are not formed during the year of the burn, which could reduce feed available for prairie chickens and wild turkeys.

Algerita (*Berberis trifoliata*), fourwing saltbush, winterfat (*Eurotia lanata*), and skunkbush sumac resprout vigorously after fire in New Mexico (Dwyer and Pieper 1967). Chickasaw plum (*Prunus angustifolia*) and aromatic sumac (*Rhus aromatica*) sprout vigorously after burning in the southern Great Plains (Jackson 1965). In the northern Panhandle of Texas, sand sagebrush is a sprouter and seedlings appear soon after fire (Jackson 1965).

Cacti are easily killed by fire, but 2 years may be required for mortality. Mortality of tasajillo following burning may exceed 80 percent (Bunting and others 1980). Walkingstick cholla and brownspine pricklypear are also easily killed by fire if they are less than 1 ft (0.3 m) high. Dwyer and Pieper (1967) found that chollas less than 1 ft (0.3 m) high were reduced by 50 percent after burning in New Mexico, but cacti over 1 ft (0.3 m) high were hardly damaged. Heirman and Wright (1973) reported similar data for West Texas. They attributed the high mortality of the shorter plants [1.5 to 2 ft (0.46 to 0.61 m)] to flame heights that will easily engulf the plants. Taller plants are not burned at the higher levels and survive fire in the shortgrass prairie. Chaining before burning will greatly increase mortality of tall walkingstick cholla plants (Heirman and Wright 1973).

FIRE EFFECTS - MIXED PRAIRIE

Grasses.--Most grasses of the mixed prairie tolerate fire during years with normal to above-normal precipitation, but sideoats grama and Texas wintergrass can be severely damaged. The rhizomatous form of sideoats grama is almost always reduced 40 to 50 percent by fire and requires 3 years for full recovery (Hopkins and others 1948; Wright 1974b). It tolerates fire reasonably well during exceptionally wet years, with only a 12 percent reduction in yield (Wink and Wright 1973). Texas wintergrass is severely harmed by sweeping hot fires (Dahl and Goen 1973), but increases following creeping, cool fires (Bean and others 1975). Fire will cause little bluestem to decrease as much as 58 percent during dry years (Hopkins and others 1948) or increase as much as 81 percent during wet years (Wink and Wright 1973).

Tobosagrass (fig. 3), a southern desert species, is prevalent on bottomland sites in the southern mixed prairie. It is a highly productive species (Paulsen and Ares 1962; Dwyer 1972) until it accumulates large amounts of litter (Wright 1969) that decays slowly (Weaver and Albertson 1956). Young tobosagrass leaves are palatable, but as plants mature and accumulate litter, they become coarse and unpalatable (Herbel and Nelson 1966; Wright 1972a; Heirman and Wright 1973).

Burning can greatly increase the production and palatability of tobosagrass during normal-to-wet years (Heirman and Wright 1973). During wet years after burning, tobosagrass will increase over 2,000 lb/acre (3 247 kg/ha). Over a series of dry, normal, and wet years (5 years), tobosagrass production increased an average of 1,030 lb/acre (1 157 kg/ha) the first growing season following a burn (Wright 1972a). Total production on burned areas increased over control areas for a 3-year period and then reached equilibrium during the fourth year after burning (Wright 1972a; Neuenschwander 1976). However, in southern New Mexico where annual precipitation is only 9 inches (23 cm), an increase in tobosagrass yields cannot be expected after burning (Dwyer 1972).

Since tobosagrass is such a coarse grass, it should be grazed within a few weeks after burning. If tobosagrass is rested for 3 or 4 months, as we generally recommend for most grasses, it will be so coarse that animals will not eat it. Cattle normally like to eat this grass during the spring and fall when it is growing rapidly. Heirman and Wright (1973) found that tobosagrass utilization could be increased many-fold following a burn. Normally, cattle only eat about 10 percent of the tobosagrass, but following a burn they will eat as much as 60 percent of the herbage (Heirman and Wright 1973).

Since tobosagrass and buffalograss often grow in combination and cattle will eat tobosagrass in preference to buffalograss during the spring after a fire (Heirman and Wright 1973), burning can be a means to increase the vigor of desirable grasses and in general improve the condition of the range. However, tobosagrass cannot take heavy utilization for an extended number of years (Canfield 1939). Maximum utilization of tobosagrass during any year probably should not exceed 50 percent.

As long as soil moisture is adequate, vine-mesquite, Arizona cottontop, plains bristlegrass, Texas cupgrass (*Eriochloa sericea*), the bunchgrass form of sideoats grama, and meadow dropseed thrive after fire (Box and others 1967; Wink and Wright 1973; Wright 1974b). Tall grama, a potentially susceptible bunchgrass after burning, yields as much forage as unburned controls during years with normal to above-normal precipitation (Wright 1974b).

Cool season annual grasses are severely harmed by spring burning. In the southern mixed prairie, spring fires severely reduce yields of the principal cool season grasses--little barley (*Hordeum pusillum*) and Carolina canary grass (*Phalaris caroliniana*). Care should be taken to not burn an entire field in early spring where these species occur. Otherwise, there will be very little green feed for animals during the subsequent winter months, although little barley is not a very palatable species.

Forbs.--Forbs that begin growth before the burning season are usually harmed by fire, whereas those that initiate growth after the burning season are usually not harmed by fire. In the southern mixed prairie, species usually harmed during the first growing season after burning include annual broomweed, horsetail conyza, plains dozedaisy (*Aphanostephus ramossissimus*), scarlet globemallow (*Sphaeralcea coccinea*), and bitterweed. Species common on burns include lambsquarters (*Chenopodium leptophyllum*), silverleaf nightshade, Carolina horsenettle (*Solanum carolinense*), and annual sunflower (*Helianthus annuus*). During the second growing season after burning, plains dozedaisy and redseed plantain (*Plantago rhodosperma*) reach their maximum importance value (Neuenschwander 1976).

In west-central Kansas, Hopkins and others (1948) found that spring burning severely harmed wild onion (*Allium nuttallii*) and perennial broomweed but left western ragweed and ashy goldenrod (*Solidago mollis*) unharmed.

Trees and shrubs.--The presence of honey mesquite and other shrubs in the southern mixed prairie before the arrival of Europeans has been well documented in the journals of Marcy (1849) and Michler (1850). Mesquite was present throughout the southern mixed prairie on uplands, also on bottomlands in the Rolling Plains (mixed prairie) but usually not on streambanks (Michler 1850). A map of Marcy's expedition shows vegetation marked as "mesquite timber" from Big Spring to the junction of the Clear Fork of the main Brazos River. This area was approximately 120 to 150 miles (194 to 242 km) long and 50 miles (81 km) wide. Throughout the rest of the Rolling Plains they recorded the continuous presence of mesquite, frequently as a lowgrowing shrub at the northern and southern extremities.

Fire was a part of the "mesquite timber" country. Michler (1850) gave the following description after leaving the Double Mountain Fork and the Clear Fork of the Brazos on his way to Big Spring, Texas:

> There was but little timber upon these streams upon first leaving the main fork, but the further we advanced the more we found, elm being the principal growth. The whole country was well timbered with mesquite, but most of it had been killed by prairie fires.

Evidently, this must have been a recent fire because Marcy and his command had traveled through the same country the previous year and did not mention the fire.

We have done considerable research on honey mesquite near Colorado City, Texas. It is in the "mesquite timber" country so designated by Marcy. Mesquite is moderately affected by fire, depending upon its age, number of dead basal stems with insect borer activity, weather at time of burning, and the amount of fine fuel for burning (Wright 1972a, 1972b; Wright and others 1976a). Unless very young, green mesquite trees are difficult to kill with one fire. Mesquite trees 1.5 years of age or younger were easily killed by fire when soil surface temperatures were above 500°F (260°C). At 2.5 years of age, they were severely harmed, but trees older than 3.5 years of age are fire resistant (table 2).

Table 2.--*Percentage of mortality of young mesquite trees after burning, in relation to age and maximum soil surface temperature*

Age	Soil surface temperature 93°C (200°F)	260°C (500°F)	427°C (800°F)	593°C (1100°F)	Unburned
Years			*percent*		
0.5	43	91	100	100	14
1.5	60	100	100	100	0
2.5	20	40	64	72	0
3.5	8	8	8	8	4
10 (Approx.)	0	0	4	8	0

Large mesquite trees that had previously been top-killed with 2,4,5-T [(2,4,5-Trichlorophenoxy) acetic acid] were killed more easily than small trees with resprouts (Britton and Wright 1971). Insect borers had infested the larger trees after the drought of the 1950's. Fire more readily consumed the wood perforated by wood borer holes. Percentage of mortality of 1,200 trees that had resprouted after spraying in 1966 and were burned in 1969 was:

	Year				
	1969	*1970*	*1971*	*1972*	*1973*
Mortality percent	10.8	17.7	22.6	25.7	26.4

First-year mortality resulted from the ignition of dead mesquite stems, which served as a fuel source to burn down into living root crowns. To achieve this effect, winds must be in excess of 8 mi/h (13 km/h) and the relative humidity must be below 40 percent at the time of burning. After the initial fire-related kill, more trees died from the weakened condition caused by interactions among fire, drought, and biotic suppression.

Junipers are quite common throughout the prairie on rocky slopes such as escarpments, ridges, or rimrocks (Wells 1970) and on areas that have been protected from fire (Penfound 1964). In Oklahoma, Arend (1950) found that fire was the worst natural enemy of eastern redcedar (*Juniperus virginiana*), a nonsprouting species. Similarly Dalrymple (1969) and Wink and Wright (1973) have found Ashe juniper, another nonsprouting species, to be highly susceptible to fire in southern Oklahoma and central Texas. These species cannot maintain themselves in areas that burn frequently (fig. 7) because the leaves are very flammable, especially during fall months, and the bark is so thin that heat from one surface fire usually kills all trees.

Figure 7.--Following dozing and prescribed burning, dense stands of Ashe Juniper can be reverted to grasslands. The oak trees were left for esthetic purposes. Note the untreated area in the upper right-hand corner.

With 500 to 1,000 lb/acre (562 to 1 124 kg/ha) of herbaceous fuel, Dalrymple (1969) obtained a 100 percent mortality of trees less than 2 ft (0.6 m) tall, 77 percent mortality of trees 2 to 6 ft (0.6 to 1.8 m) tall and 27 percent mortality of trees over 6 ft (1.8 m) tall, for an average mortality of 68 percent.

Where fine fuel was at least 1,100 lb/acre (1 236 kg/ha), Wink and Wright (1973) found that 99 percent of the Ashe juniper trees less than 6 ft (1.8 m) tall were killed by fire under the following weather conditions: air temperatures 75° to 85°F (24° to 29°C), relative humidity 25 to 35 percent, wind 10 to 15 mi/h (16 to 24 km/h). If fine fuel was above 2,500 lb/acre (2 890 kg/ha) all juniper trees were killed by fire. With 750 lb/acre (843 kg/ha) of fine fuel, Dwyer and Pieper (1967) reported that 70 percent of the juniper trees exposed to high temperatures of a summer wildfire had died by the following year.

Redberry juniper, a sprouting species on rough breaks in the Rolling Plains, is very difficult to kill by fire unless the trees are under 12 years of age (Smith and others 1975). However, fires reduce the sphere of influence of the trees. Very little forage grows under juniper trees. When the trees are burned, they shade less area, and grasses and forbs encroach.

Several shrub species are present in the mixed prairie of the southern Great Plains, but they are less abundant than trees. Fourwing saltbush, a palatable shrub, thrives after fire. It is a vigorous sprouter and appears to have fully recovered by 3 years after burning. Lotebush also sprouts after a fire, but requires about 6 years to recover 75 percent of its original canopy cover. Littleleaf sumac (*Rhus microphylla*) and algerita sprout following fires, but we have relatively little research data on these species in West Texas. Smoothleaf sumac and all species of oak are vigorous sprouters in Ashe juniper communities of the Edwards Plateau. Cacti are abundant in the mixed prairie and equally susceptible to fire as mentioned for the shortgrass prairie.

FIRE EFFECTS - MIXED TALLGRASS--FOREST

The Cross Timbers region occupies a sandy belt of land in east-central Texas and eastern Oklahoma. It contains post oak and blackjack oak as well as many tallgrass species. Both oak species are easily top-killed with fire but resprout vigorously. Many ranchers feel that it is no longer economical to use goats or chemicals to keep oak sprouts suppressed in bluestem pastures. Presently, there is interest in determining whether a 4-year burning rotation will be effective. However, fire research has not been done in the area and the natural role of fire is unclear.

Central Great Plains

DISTRIBUTION, CLIMATE, SOILS, AND VEGETATION

The central Great Plains extend from the foothills of the Rockies in eastern Colorado and southeastern Wyoming eastward through Kansas and Nebraska to grassland-forest communities in northwest Missouri, southern Iowa, and Illinois. Shortgrass prairie (fig. 8) lies primarily in eastern Colorado, but it also occurs in western Kansas, southeastern Wyoming, and the extreme portion of western Nebraska. Annual precipitation varies from 11 to 18 inches (28 to 46 cm). Surface soil textures are largely sand, sandy loam, loamy sand, loam, and silt loam. Elevation drops from 5,000 or 6,000 ft (1 524 to 1 829 m) along the foothills in Colorado to 3,000 ft (915 m) on the eastern edge of the shortgrass prairie in Kansas. In Nebraska the eastern elevations vary from 4,000 to 5,000 ft (1 219 to 1 524 m).

Figure 8.--Shortgrass prairie in the central Great Plains of eastern Colorado. Dominant grasses are blue grama, buffalograss, and western wheatgrass.

Buffalograss, blue grama, western wheatgrass, and scarlet globemallow are the dominants on loams and silt loams. Ranges in good-to-excellent condition will also support green needlegrass (*Stipa viridula*). Sandy-textured soils are dominated by blue grama, prairie sandreed (*Calamovilfa longifolia*), and needle-and-thread (*Stipa comata*). Other grasses and grass-like species include red threeawn, sand dropseed, and sunsedge. Well-managed ranges in eastern Colorado could also support sand bluestem, switchgrass, and Indiangrass. Dominant forbs and shrubs are western ragweed, bush morningglory (*Ipomea leptophila*), herbaceous sage (*Artemisia ludoviciana*), and fourwing saltbush.

East of the shortgrass prairie lies mixed prairie in western Nebraska and Kansas. There is tallgrass prairie, however, in the Sandhills of northwestern Nebraska. Elevation along the western edge of the mixed prairie in Kansas is 3,000 ft (915 m) but rises to as much as 5,000 ft (1 524 m) along the western edge of the Sandhills of Nebraska. Elevation starts at 1,300 ft (396 m) along the eastern edge in southern Kansas and rises to as much as 2,000 ft (610 m) in north-central Nebraska. Precipitation varies from 18 to 28 inches (46 to 71 cm) in Kansas and 18 to 25 inches (46 to 64 cm) in Nebraska. Topography varies from undulating-to-rolling ridgetops, gently sloping, and hilly with steeply sloping valley sides. Soil textures are sand, silt, loam, silt loam, silty clay loam, and clay uplands.

Dominant grasses in the mixed prairie of the central Great Plains are blue grama, little bluestem, sand dropseed, tall dropseed (*Sporobolus asper*), western wheatgrass, buffalograss, sideoats grama, purple threeawn (*Aristida purpurea*), needle-and-thread, junegrass (*Koeleria cristata*), and occasional sand bluestem, prairie sandreed, and switchgrass plants. Western wheatgrass and needle-and-thread become more prevalent northward from Kansas into Nebraska. Common forbs include scarlet globemallow, western ragweed, resindot skullcap (*Scutellaria resinosa*), prairie coneflower (*Ratibida columnaris*), heath aster (*Aster ericoides*), black sampson (*Echinacea angustifolia*), prairie phlox (*Phlox pilosa*), prairie clover (*Petalostemum purpureum*), dotted gayfeather (*Liatris punctata*), slim-flowered scurfpea (*Psoralea tenuiflora*), Missouri goldenrod (*Solidago missouriensis*), and many others. Western ragweed and annual sunflowers are abundant on heavily grazed sites.

Tallgrass prairie in the eastern third of Nebraska, northern Iowa, and east-central Kansas varies in elevation from 1,000 to 2,000 ft (305 to 610 m). Annual precipitation varies from as low as 23 inches (58 cm) in eastern Nebraska to as much as 35 inches (89 cm) along the eastern edge of the tallgrass prairie. The Sandhills in western Nebraska, a westward extension of the tallgrass prairie has precipitation as low as 18 inches (46 cm) per year. With the exception of the Sandhills of Nebraska and the Flint Hills of Kansas, most of the soils are medium textured. Soils in the Flint Hills are primarily Lithosols and topography is gently rolling.

Grasses of the tallgrass prairie (fig. 9) are primarily little bluestem, big bluestem, switchgrass, Indiangrass, and prairie dropseed (*Sporobolus heterolepis*). Other grasses include Canada wildrye (*Elymus canadensis*), porcupine grass (*Spartina pectinata*), and eastern gamagrass (*Tripsacum dactyloides*). Additional species in the Sandhills of Nebraska are prairie sandreed and sand bluestem. Important shrubs include western snowberry (*Symphoricarpos occidentalis*), inland ceanothus (*Ceanothus ovatus*), lead plant, willow (*Salix* sp.), gooseberry (*Ribes* sp.), and prairie rose (*Rosa arkansana*). A wide variety of forbs occur in tallgrass prairie (Weaver and Clements 1938; Weaver and Albertson 1956). Typical genera include *Aster, Solidago, Silphium, Helianthus, Astragalus, Baptisia, Callinhoe, Phlox, Sisyrinchium, Lithospermum, Viola, Anemone, Tradescantia, Psoralea, Erigeron, Petalostemon, Glycyrrhiza, Echinacea, Liatris, Vernonia, Coreopsis, Bidens, Kuhnia, and Carduus*. Trees of the tallgrass prairie include American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*), eastern redcedar, bur oak (*Quercus macrocarpa*), chinquapin oak (*Q. muhlenbergii*), eastern redbud (*Cercis candensis*), bitternut hickory (*Carya cordiformis*), and roughlead dogwood (*Cornus drummondii*) (Smith and Owensby 1972; Bragg and Hulbert 1976).

Tallgrass prairie and forest combinations (fig. 10) extend eastward into eastern Kansas, northwestern Missouri, southern Iowa, and Illinois. The tallgrass species are those of the tallgrass prairie and the forest is oak-hickory (*Quercus-Carya*). Precipitation increases to as much as 40 inches (102 cm) per year and elevation drops to 500 ft (152 m).

FIRE EFFECTS - SHORTGRASS AND MIXED GRASS PRAIRIE

Prescribed fire research has not been conducted in plant communities of the central Great Plains. Hopkins and others (1948) and Launchbaugh (1964) studied the effects of wildfire. Following dry years, Hopkins and others (1948) found that the cover and yield of big bluestem, little bluestem, hairy grama (*Bouteloua hirsuta*), sideoats grama, buffalograss, hairy sporobolus (*Sporobolus pilosus*), and blue grama were reduced by fire; undesirable broadleaved plants, principally western ragweed, increased. Similarly, Launchbaugh (1964) found that buffalograss, blue grama, and western wheatgrass did not fully recover after fire until the third growing season.

Figure 9.--Tallgrass prairie in the Flint Hills of Kansas. Rocky surface soils prevent cultivation. Dominant grasses are little bluestem, big bluestem, and Indiangrass.

Figure 10.--Mixed grassland-forest combination in Missouri. This range is in poor condition, but would support tallgrasses if managed properly.

Based on data recorded during wet years in the southern Great Plains, there is no benefit to burning the shortgrass prairie unless there is a need to improve grazing distribution or there are unusually heavy accumulations of litter that need to be removed. Therefore, it is difficult to justify prescribed burning research in the essentially shrubless shortgrass prairie of the central Great Plains. Most of the mixed prairie is in wheat, so there is very little need for prescribed burning research in this region.

FIRE EFFECTS - TALLGRASS PRAIRIE

General comments.--Where the eastern plains have a permanently moist subsoil, Shantz and Zon (1924) suggested that the grassland had been induced by fire and drought. The environment is suited to trees when fire is absent. Work by Kucera (1960), Blan (1970), and Bragg and Hulbert (1976) support this theory. Aerial photography by Bragg and Hulbert (1976) in the Flint Hills bluestem prairie showed that on unburned pastures the combined tree and shrub cover increased 34 percent from 1937 to 1969. Tree cover alone increased 24 percent from 1856 to 1969. Invasion by trees was greatest on the deep, permeable, lowland soils. Woody plants increased only slightly on the droughty upland soils. Based on this data, Bragg and Hulbert (1976) concluded that burning had been effective in restricting woody plants to natural, presettlement levels. For Minnesota and Nebraska, however, Weaver (1954) concluded that "over most of the territory it seems probable that shrubs and woodland could not extend their areas greatly even if unhandicapped by mowing and prairie fires."

The incentive for burning in the Flint Hills of Kansas was stimulated initially by lease arrangements in the 1880's for transient steer grazing. Lessees required that the lands be burned (Kollmorgen and Simonett 1965) because the forage had higher nutritional value after burning. Livestock gains were 25 lb (11.3 kg)/steer higher on late spring burns than on adjacent unburned pastures (Smith and Owensby 1972) and growth began 7 to 10 days earlier on burned plots (Kucera and Ehrenreich 1962). Penfound and Kelting (1950) demonstrated that cattle will eat more litte bluestem on burned rangeland.

Grasses.--The effect of fire on grasses depends on the site, the amount of soil moisture, and the frequency of burning. However, there is reasonably good agreement among many authors about the effect of fire on grasses in the tallgrass prairie. Big bluestem almost always increases after burning (Robocker and Miller 1955; Kucera and Ehrenreich 1962; McMurphy and Anderson 1965; Hulbert 1969; Anderson and others 1970). Hadley and Kieckhefer (1963) noted a 275 percent increase in big bluestem 1 year after burning in Illinois, which is indicative of a decadent plant community before it is burned. Likewise Indiangrass increases after burning (Dix and Butler 1954; Robocker and Miller 1955; Kucera and Ehrenreich 1962; Hadley and Kieckhefer 1963; Anderson and others 1970).

Switchgrass has not been studied as intensively as the previous two species. However, Robocker and Miller (1955) found that it increased after burning. In a study by Anderson and others (1970), there was relatively little switchgrass in the plots and no change was detected. In a study where mulching was applied to plots, the yields of switchgrass decreased with increased mulching (Weaver and Rowland 1952).

Little bluestem also increases after single burns in the true prairie (Hensel 1923; Aldous 1934; Penfound and Kelting 1950; Dix and Butler 1954; Robocker and Miller 1955; Kucera and Ehrenreich 1962). Anderson and others (1970) did not find any change in production of little bluestem after 8 years of consecutive annual burning, provided the burns were conducted in late spring (May 1). Early spring (March 20) burns reduced yields as much as 25 percent (McMurphy and Anderson 1965; Owensby and Anderson 1967). Soil moisture has to be considerably below normal in this rainfall zone for fire to harm little bluestem (Box and White 1969).

Sideoats grama generally does not change in yield after burning (Hensel 1923; Robocker and Miller 1955; Anderson and others 1970; Smith and Owensby 1972). Other grasses that increase following early spring or winter burning include prairie junegrass (McMurphy and Anderson 1965), sand dropseed (Hensel 1923), blue grama, and hairy grama (Anderson and others 1970). Buffalograss was unchanged after 17 consecutive annual burns (Anderson and others 1970).

Cool-season grasses, particularly the introduced species, are severely harmed by spring burning. Many authors (Hensel 1923; Ehrenreich 1959; Hadley and Kieckhefer 1963; Old 1969) have reported that Kentucky bluegrass (*Poa pratensis*) decreased 80 percent or more following a spring burn. Curtis and Partch (1948) found that Canada bluegrass (*Poa compressa*) and Kentucky bluegrass were severely damaged by spring burning. Similarly, Canada wildrye and Virginia wildrye (*Elymus virginica*) (Robocker and Miller 1955), Japanese brome (*Bromus japonicus*) (McMurphy and Anderson 1965), and smooth brome (*B. inermis*) (Old 1969) are all damaged by fire. Smooth brome and similar species which begin growth about mid-May are only inhibited by burning, whereas early growing species such as Kentucky bluegrass are almost eliminated by burning (Old 1969). Fall witchgrass (*Leptoloma cognatum*) is favored by spring fires (Penfound 1964).

Kucera (1970) proposed a 3-year burning interval to maintain tallgrass dominance, as well as to retain the species diversity typical of the native prairie community.

Forbs.--Late spring burning reduces all forbs (McMurphy and Anderson 1965), although the composition of forbs is changed relatively little (Anderson 1965). Major forbs that are harmed by fire include *Petalostemum* species (Hadley 1970), heath aster and *Solidago* species (Kucera and Koelling 1964). Plains wildindigo (*Babtisia leucophilia*) is favored by fire (Anderson 1965).

Wolfe (1972) studied the effects of a spring wildfire on a prairie sandreed-bluestem association in the Nebraska Sandhills. Herbage growth was reduced as much as 45 percent. Most of the decreaser forbs increased after fire while the increaser forbs declined. Forbs increasing after burning included prairie sunflower (*Helianthus petiolaris*), dotted gayfeather, Missouri goldenrod, false boneset (*Kuhnia eupatorioides*), and silky prairieclover (*Petalostemum villosum*). Those that decreased were pepperweed (*Lepedium* sp.), Virginia dayflower (*Commelina virginica*), woolly plantain, goosefoot, prairie coneflower, pigweed (*Amaranthus* sp.), and puccoon (*Lithospermum ruderale*). Western ragweed and Missouri spurge (*Euphorbia missurica*) remained unchanged.

Shrubs and trees.--There are relatively few species of shrubs in the tallgrass prairie. The shrubs favored by fire include smoothleaf sumac, lead plant (Anderson and others 1970), and western snowberry (*Symphoricarpos occidentalis*) (Pelton 1953). Coralberry (*Symphoricarpos orbiculatus*) is slightly harmed by annual spring burning, but will increase dramatically if protected from fire (McMurphy and Anderson 1965).

Eastern redcedar and western snowberry will invade a protected prairie (Penfound 1964). American elm seedlings establish early after a burn (McMurphy and Anderson 1965), but a later fire will remove the seedlings.

Seed yields.--Several articles (Burton 1944; Curtis and Partch 1950; Kucera and Ehrenreich 1962; Old 1969) have shown that herbage removal or burning increases flower stalk production. Burton (1944) reported an increase in seed yield in burned, grazed, or mowed prairie compared with ungrazed, unburned areas. Curtis and Partch (1950) working in Wisconsin reported a 6-fold increase in flowering on clearcut sites when compared to unburned areas. The increase was equivalent to that recorded on burned areas. Kucera and Ehrenreich (1962) also found that flower stalks were more numerous on burned areas. The main species affected were big bluestem, little bluestem, and Indiangrass. Quadrat counts in 1960 showed percentage increases attributable to burning of 270, 1,200, and 400 respectively.

A detailed study of the effect of litter and burning on flower stalk production was conducted by Old (1969). Cutting and raking increased the number of flower stalks for 2 years. Burning caused a greater increase in flowering, however, than did cutting (table 3). Seed yields increased because of litter removal, the removal of competing cool season plants, and increased nitrification. The increased soil temperatures after fire stimulated nitrification. The addition of ash had no effect, but the addition of 200 lb/acre (225 kg/ha) of nitrogen fertilizer increased seed yield more than burning.

Table 3.--*The effect of various herbage removal treatments on flowering in the tallgrass prairie*[1]

Treatment	Number of flower stalks	
	First year	Second year
Burning	102	74
Cut and raked	66	63
Cut and left	29	52
Undisturbed	11	34

[1]Data from Old (1969).

Litter.--Prairie closed to both grazing and fire soon begins to deteriorate (Anderson and others 1970). Accumulation of mulch depresses herbage yield and reduces the number of plant species (Weaver and Tomanek 1951; Ehrenreich 1959). Most of the decreases are associated with lower soil temperatures (Peet and others 1975).

Reduced herbage yield associated with increased litter is due in part to the amount of ammonium nitrogen. Rice and Pancholy (1973) found that the amount of ammonium nitrogen was lowest in the first successional stage, intermediate in the intermediate successional stage, and highest in the climax. The amount of nitrate nitrogen was highest in the first successional stage, intermediate in the intermediate successional stage, and lowest in the climax. The data indicate that the nitrifiers are inhibited in the climax stage so that ammonium nitrogen is not oxidized to nitrate as readily in the climax as in earlier successional stages.

Northern Great Plains

DISTRIBUTION, CLIMATE, SOILS AND VEGETATION

The northern Great Plains include the eastern two-thirds of Montana, eastern third of Wyoming, North Dakota, South Dakota, and the western edge of Minnesota. A large part of Minnesota, however, is a mixture of grassland and forest communities. This region extends 250 miles (403 km) into southeastern Alberta, southern Saskatchewan, and the southwestern tip of Manitoba (Moss 1955; Rowe 1972). The plant associations include mixed prairie, tallgrass prairie, fescue prairie, and aspen parkland. The shortgrass association does not occur in the northern Great Plains. The mixed prairie includes eastern Montana, eastern Wyoming, all but the eastern edges of North Dakota and South Dakota, as well as the southeastern portion of Alberta and southern Saskatchewan.

Precipitation varies from 10 to 24 inches (25 to 61 cm), with the driest areas located on the western edge of the mixed prairie. Soil textures are primarily sand, sandy loam, silt loam, silty clay loam, and loam. Most soils have developed from glacial till north of the 48th parallel. The last continental ice sheet left the region about 12,000 years ago. Elevation varies from 1,300 to 4,000 ft (396 to 1 219 m). The highest elevations occur in eastern Wyoming and southeastern Montana. From this high, rolling topography, elevation drops to 3,000 ft (915 m) in northern Montana and southern Alberta and then to 1,300 ft (396 m) in the eastern parts of the northern Great Plains. Topography in northern Montana and the central Dakotas is level to gently rolling, with abrupt breaks in many areas.

Annual precipitation averages 10 to 12 inches (25 to 30 cm) in the most arid parts of eastern Wyoming, and Montana, southeastern Alberta, and southwestern Saskatchewan (fig. 11). The grasses and sedges are mainly blue grama, needle-and-thread, green needlegrass, western wheatgrass, thickspike wheatgrass (*Agropyron dasystachyum*), threadleaf sedge (*Carex filifolia*), Sandberg's bluegrass (*Poa secunda*), plains muhly (*Muhlenbergia cuspidata*), little bluestem, and junegrass. Forbs are not very abundant, but pussytoes (*Antennaria* sp.), moss phlox (*Phlox hoodii*), little club moss (*Selaginella densa*), scarlet globemallow, black sampson, silverleaf scurfpea (*Psoralea argophylla*), prairie crocus (*Anemone patens* var. *wolfgangiana*), Missouri goldenrod, and others are representative species. Shrubs are predominantly fringed sage (*Artemisia frigida*), silver sage (*A. cana*), Nuttall saltbush (*Atriplex nuttallii*), winterfat, and plains pricklypear.

Figure 11.--Semi-arid mixed prairie (dry mixed prairie) in eastern Wyoming. Dominant species are blue grama, western wheatgrass, and needle-and-thread.

The more mesic portions of the mixed prairie (fig. 12) average 13 to 18 inches (33 to 46 cm) annual precipitation. This section occupies an arc to the north and east of the more arid areas, occurring in Alberta, Saskatchewan, North Dakota, and South Dakota. Many grass species of the arid section occur in the mesic mixed prairie along with other species. Western porcupine grass (*Stipa spartea* var. *curtiseta*) and thickspike wheatgrass are usually codominants in the Canadian sections (Coupland 1950). In North Dakota these same species are present with increasing amounts of needle-and-thread, little bluestem, junegrass, blue grama, green needlegrass, and prairie sandreed. In South Dakota, the dominant grasses are little bluestem, big bluestem, needle-and-thread, gum needlegrass, junegrass, blue grama, and western wheatgrass as well as numerous sedges. Kentucky bluegrass and smooth bromegrass, cool-season exotics, have invaded much of the northern mixed prairie in the absence of fire (Kirsch and Kruse 1972).

A variety of forbs (about 25 percent total yield) normally occur in the mixed prairie, but major species include locoweed (*Astragalus* and *Oxytropis* sp.), heath aster, aromatic aster (*Aster oblongifolius*), wild onion, American vetch (*Vicia americana*), Missouri goldenrod, woolly plantain, penstemon (*Penstemon* sp.), slim-flowered scurfpea, hairy golden-aster (*Chrysopsis villosa*), moss phlox, little club moss, wild lettuce (*Lactuca pulchella*), western yarrow (*Achillea millefolium*), plains erysimum (*Eyrsimum capitatum*), scarlet gaura (*Gaura coccinea*), white milkwort (*Polygala alba*), annual sunflower, herbaceous sage, and dotted gayfeather. Dominant invaders include summer cypress, yellow sweetclover (*Melilotus officinalis*), gumweed (*Grindelia squarrosa*), and foxtail barley (*Hordeum jubatum*), A number of shrubs are present, which include fringed sage, western snowberry, russet buffalograss (*Sheperdia canadensis*), silverberry (*Elaeagnus commutata*) rose, plains pricklypear, perennial broomweed, Nuttall saltbush, fourwing saltbush, lead plant, willow, and wild plum.

Figure 12.--Mesic mixed prairie in east-central North Dakota. Dominant grasses are thickspike wheatgrass, western wheatgrass, junegrass, green needlegrass, western porcupine grass, Canada wildrye, sedges, and little bluestem. Fire can be used in this vegetation to control introduced cool-season grasses such as Kentucky bluegrass and smooth bromegrass.

The tallgrass prairie region, which is mostly under cultivation (fig. 13), occupies the eastern edge of North Dakota and South Dakota, the western edge of Minnesota, and the southwestern corner of Manitoba. Surface soil textures are primarily loam, silt loam, and silty clay loam. Elevation varies from 800 to 1,800 ft (244 to 549 m), and topography varies from a level to gently rolling glacial plain. Precipitation varies from 18 inches (46 m) in southwestern Manitoba to 30 inches (76 cm) in south-central Minnesota. Most tallgrasses on native lands are similar to those in the tallgrass prairie of the central Great Plains. However, cool-season grasses such as porcupine grass (*Stipa spartea*), bearded wheatgrass (*Agropyron subsecundum*), quackgrass (*A. repens*), slender wheatgrass (*A. trachycalum*), smooth bromegrass, and Kentucky bluegrass, are most abundant as codominants with the bluestems, switchgrass, prairie cordgrass, and Indiangrass. The shrubs, silverberry, and fringed sage occur in addition to western snowberry, prairie rose, and smoothleaf sumac. Forbs are very similar to those mentioned for tallgrass prairie in the central Great Plains.

Fescue prairie occupies the eastern foothills of the Rocky Mountains in northwestern Montana and southwestern Alberta. It also occurs in the aspen parkland of central ALberta and Saskatchewan (fig. 14), extending eastward to southwestern Manitoba. Throughout the mixed prairie in Canada, patches of fescue grassland occur on north-facing slopes and at higher elevations where the precipitation is most effective (least evaporation). Annual precipitation ranges from 14 to 18 inches (36 to 46 cm) in the aspen parkland to 15 to 24 inches (38 to 61 cm) in the foothills. Soil textures are primarily sandy loam, and loam. Most of the area has been glaciated. Fescue grasslands occur at elevations as high as 7,500 ft (2 287 m) in the Rocky Mountains in Canada. Most foothill fescue grasslands are at 3,500 to 6,000 ft (1 067 to 1 829 m). Fescue grasslands in the parklands are at 2,000 ft (610 m) in central Alberta, descending gradually to 1,200 ft (366 m) in southeastern Manitoba. The greatest topographic relief is in the Rocky Mountain foothills. Plains topography ranges from level to sharply rolling.

Figure 13.--Tallgrass prairie in eastern North Dakota, with marsh area.

Figure 14.--Fescue prairie in the aspen parkland of Edmonton, Alberta. Dominant grass is rough fescue with some western porcupine grass.

The fescue prairie can be divided into two sections: a foothills and mountain flora, and a plains or aspen parkland flora. Mountain glaciers left a number of areas uncovered, providing a refuge for the flora. The foothills fescue prairie is a species-rich flora. Continental glaciers apparently eliminated some species from the plains region. About 50 species present in the fescue prairie of the foothills are absent from the fescue prairie in central Alberta and Saskatchewan.

Grasses in the foothills region include the dominant, rough fescue (*Festuca scabrella*), Parry's oatgrass (*Danthonia parryi*), Idaho fescue (*Festuca idahoensis*), bluebunch wheatgrass (*Agropyron spicatum*), intermediate oatgrass (*Danthonia intermedia*), slender wheatgrass, and Hooker's oatgrass (*Helictotrichon hookeri*). Timothy (*Phleum pratense*), Kentucky bluegrass, and smooth bromegrass are now common exotic species in valley bottoms and on lower slopes. In foothills, rough fescue is a 3-ft (0.9-m) tall, 10- to 20-inch (25- to 51-cm) diameter bunchgrass (Moss and Campbell 1947), but in parklands is an 18-inch (46-cm) tall, 1- to 2-inch (2.5- to 5.1-cm) diameter bunchgrass having short rhizomes. Western porcupine grass is frequently codominant with rough fescue in central Alberta and Saskatchewan. Parry's oatgrass, Idaho fescue, and bluebunch wheatgrass are absent. Several grasses from the mixed prairie frequently occur. They include thickspike wheatgrass, blue grama, needle-and-thread, and prairie sandreed. Cool-season grasses from the Boreal forest that occur throughout the fescue prairie on more mesic sites include narrow reedgrass (*Calamagrostis neglecta*), northern reedgrass (*C. inexpansa*), tufted hair grass (*Deschampsia caespitosa*), hairy brome (*Bromus ciliatus*), sweetgrass (*Hierochloe odorata*), and purple oatgrass (*Schizachne purpurascens*). The common sedges are blunt sedge (*Carex obtusata*), sun sedge, Pennsylvania sedge, and low sedge.

Foothill grasslands are rich in forbs, including yarrow, pussytoes, herbaceous sage, purple aster (*Aster laevis*), milk vetch, balsamroot (*Balsamorhiza sagitata*), sticky geranium (*Geranium viscosissimum*), hedysarum (*Hedysarum americanum*), dotted gayfeather, puccoon, lupine, vetch, and death camas (*Zygadenus gramineus*). Forbs are less important in fescue grasslands of the parklands and include yarrow, pussytoes, herbaceous sage, purple aster, milk vetch, Missouri goldenrod, buffalo bean, prairie crocus, moss phlox, American vetch, northern bedstraw (*Galium boreale*), and wild strawberry (*Fragaria virginiana*).

Shrubby cinquefoil (*Potentilla fruticosa*) increases with grazing intensity in fescue grasslands of the foothills, but it does not extend into the plains northeast of Calgary. Other shrubs common throughout the fescue grasslands include silverberry, western snowberry, willow, roses, fringed sage, and serviceberry. The trees, aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*), are invading the more mesic sites throughout the fescue grasslands. Willows and conifers [white spruce (*Picea glauca*), Douglas-fir (*Pseudotsuga menziesii*)] are also invading many grasslands in the Rocky Mountain foothills because of the cessation of wildfires. If trees remain, the soils are expected to change from the productive black chernozems to less productive, less fertile, grey luvisols (Dormaar and Lutwick 1966).

FIRE EFFECTS - SEMIARID MIXED PRAIRIE [Precipitation less than 15 inches (38 cm) in the United States and less than 13 inches (33 cm) in Canada]

Prescribed burning has been studied only in the arid portion of the mixed prairie (Clarke and others 1943). The study evaluated effects of spring and fall burning of *Stipa-Bouteloua* and *Agropyron smithii-A. dasytachyum* ranges in southeastern Alberta. Coupland (1973) and DeJong and MacDonald (1975) have studied the effect of an August wildfire on equivalent *Agropyron* sites in southwestern Saskatchewan. All fires reduced herbage yield. Coupland (1973) found that 1 year after the burn, production of western and thickspike wheatgrass was reduced 19 percent, junegrass was reduced 63 percent, low sedge was increased 36 percent, and green needlegrass was increased 45 percent. Total grass production was reduced 13 percent. At the end of the three growing seasons, current growth was 69 to 73 percent of unburned areas. DeJong and MacDonald (1975) also studied the effects that an August wildfire had on soil moisture regime. Major effects of burning were reduction in soil moisture recharge the first winter after the fire and lower water use the growing season following burning. Less efficient moisture storage on the burned site was probably due to snow blowing off the area. By the second winter, soil moisture recharge was the same on burned and unburned grasslands. However, soil moisture continued to be lower under burned grassland throughout the first and second growing seasons after fire. Apparently, the wildfire reduced soil moisture infiltration rate on the clay soils for at least the first 2 years.

Increased water stress on plants of the burned site was measured by Redmann (1978). Both water potential and osmotic potential of leaves of thickspike wheatgrass and junegrass were lower on the burned areas. The primary effect of burning appeared to be an alteration of micro-climate, resulting in the development of an unfavorable plant and soil water status. Duration of this detrimental effect is not known. However, annual herbage production was still 28 percent less on burned than on unburned plots by the third growing season after the wildfire.

Clarke and others (1943) found that prescribed burning in the spring reduced yield 50 percent the first year and 15 percent the second year, with full recovery the third year. Fall burning decreased yield by about 30 percent the first year after burning with no significant reduction thereafter. The wheatgrass type (western wheatgrass-thickspike wheatgrass) was more detrimentally affected than the communities dominated by blue grama and needle-and-thread. Vegetation did not recover as rapidly on grazed pastures as on the ungrazed experimental plots. It took 3 to 5 years for a

burned and grazed pasture to regain normal productivity. The vegetation response is similar to that reported by Hopkins and others (1948) and Launchbaugh (1964) in the shortgrass prairie of the central and southern Great Plains.

Research results indicate no apparent benefits from burning herbaceous species in the arid mixed prairie where wheatgrasses predominate. Research done on needle-and-thread and green needlegrass is inadequate to determine response to prescribed fire. However, data from Coupland (1973) and comments by Clarke and others (1943) lead us to believe that the needlegrasses are not as detrimentally affected by fire as are the wheatgrasses. On the other hand, fire will kill silver sagebrush (Rowe 1969), fringed sage, and little club moss (Dix 1960), and will reduce the vigor of western snowberry. Research data indicate that more than 3 years must be allowed for full recovery of the range under grazing (Clarke and others 1943). Such a long rest would be a high price to pay for shrub control and may not be necessary. Precipitation on the northern Great Plains follows dry and wet cycles. Prescribed burning may be a useful management tool for the control of shrubs and little club moss following winters with above normal precipitation. Only meticulous research will provide the answers.

FIRE EFFECTS - MESIC MIXED PRAIRIE [Precipitation 15 to 18 inches (38 to 48 cm)/year in United States; precipitation may be as low as 13 inches (33 cm) in Canada]

Dix (1960) studied the effect of three wildfires (May, August, September - all subject to trespass grazing) in western North Dakota where annual precipitation averaged 16 inches (41 cm). He found that a hot, late-May wildfire reduced the frequency of bearded wheatgrass, blue grama, prairie sandreed, needle-and-thread, and green needlegrass. The frequency remained the same or higher for western wheatgrass, low sedge, threadleaf sedge, Pennsylvania sedge, junegrass, and Plains muhly. However, herbage yield might have been reduced for several years. Frequencies of fringed sage, Arkansas rose, and silverleaf scurfpea were significantly reduced, whereas most forbs remained unchanged. Following a fall burn, the long-term evaluations (4 years), showed relatively few changes in botanical composition except for a possible reduction in threadleaf sedge, fringed sage, leafy spurge (*Euphorbia esula*), and little club moss. *Hedeoma hispida*, stickseed (*Lappula redowski*), and herbaceous sage increased. Pennsylvania sedge, prairie sandreed, hairy golden-aster, and wild lettuce were harmed by the late summer fire, but no explanation was given.

On a similar mixed prairie site in Wind Cave National Park in South Dakota, Schripsema (1977) found that an early spring burn (April 21, 1976) increased western wheatgrass, needle-and-thread, buffalograss, and blue grama. Green needlegrass, bluegrasses, and forbs decreased, whereas sedges showed no change. Yields following the same burn in a drier year (1977) showed similar trends except for decreases in needle-and-thread and sedges. Forb composition was similar to the controls. Thus, green needlegrass and the exotic bluegrasses are quite susceptible to early spring burns, but most other grasses are tolerant of such burns if there is moisture in the soil at the time of the burn.

Bluestem sites of the forest-grass ecotone in the Black Hills area (fig. 15) are more tolerant of prescribed fires (Gartner and Thompson 1972; Schripsema 1977). Annual precipitation is 15 to 17 inches (38 to 43 cm). A late spring burn (May 27, 1976) increased little bluestem 31 percent, big bluestem 20 percent, forbs 108 to 405 percent, and decreased bluegrasses 65 percent (Schripsema 1977). Silverleaf scurfpea and slim-flowered scurfpea were two forbs that increased noticeably. Minor amounts of western wheatgrass, buffalograss, and blue grama and needlegrasses were present. Western wheatgrass decreased and the other species increased. On the other hand, a winter burn (March 1, 1977) had almost the reverse effect. Big and little bluestem were severely harmed. Western wheatgrass and the needlegrasses increased, and bluegrasses were reduced only 28 percent. Thus, late spring burns during years with normal to above-average precipitation are the most preferable to increase herbaceous yields of desirable grasses and achieve desired compositional changes.

Figure 15.--Mixed prairie that borders the Black Hills of South Dakota. Little bluestem and big bluestem are the dominant grasses. Fire can be used in this vegetation to keep young pines from spreading into the grasslands.

Kirsch and Kruse (1972) studied the effects of prescribed spring fire on vegetation at the extreme eastern edge of the mixed prairie in east-central North Dakota, near the tallgrass prairie. Annual precipitation averages 17.5 inches (44 cm). Their purpose in burning was to improve wildlife habitat. The warm season grasses, big and little bluestem, prairie sandreed, blue grama, and Leiberg panicum (*Panicum leibergii*) increased in cover after burning. So did the three needlegrasses, needle-and-thread, western porcupine grass, and green needlegrass. Bearded and western wheatgrass maintained themselves with burning but declined in unburned areas (Kirsch, Wildlife Biologist, U.S. Fish and Wildl. Serv., Woodworth, N.D., personal communication). Kentucky bluegrass had high foliar cover before burning in 1969 but was nearly eliminated by three consecutive fires. Quackgrass and smooth bromegrass continued to expand on unburned plots but were not present on burned plots.

Most forbs either increased in cover or did not change. Major forb increasers after burning included western ragweed, meadow anemone (*Anemone canadensis*), candle anemone (*A. cylindrica*), prairie crocus (*A. patens*), heath aster, prairie chickweed (*Cerastium arvense*), Maximilian sunflower (*Helianthus maximiliani*), purple prairie clover, and silverleaf scurfpea. Most other forbs, including western yarrow, herbaceous sage, bedstraw, and goldenrod did not change appreciably. The shrubs, fringed sage, prairie rose, and western snowberry, also did not change appreciably. Canada thistle decreased greatly after burning.

FIRE EFFECTS - TALLGRASS PRAIRIE

A classic account of the effect of fire on tallgrass prairie concerns rejuvenation of the Curtis Prairie in Wisconsin (Curtis and Partch 1948; R. Anderson 1972). This particular area was abandoned from cultivation in 1932. By 1936 the principal perennials were quackgrass, Kentucky bluegrass, and Canada bluegrass (Curtis and Partch 1948). Various annuals were also present. A number of prairie forbs and grasses were transplanted into the area in 1936 and 1937 at a density of 2.6 plants per 100 ft^2 (2.8 plants per 10 m^2). It was soon evident that the species were not maintaining themselves against the bluegrass sod. Fire was introduced experimentally to test the desirability of burning, the best season and frequency of burning. Since 1950, one-half to two-thirds of the 20-acre (8.1-ha) prairie has been burned every year.

Annual burning between 1941 and 1946 reduced bluegrass sod by 80 percent and permitted big bluestem, rattlesnake master (*Eryngium yuccifolium*), goldenrod (*Solidago rigida*), tall gayfeather (*Liatris aspera*), common ragweed (*Ambrosia artemisiifolia*), heath aster, and erigeron (*Erigeron annua*) to increase. Atlantic wildindigo (*Baptisia leucantha*) was not affected by fire and purple coneflower (*Echinacia purpurea*) was the only species reduced by burning. A more recent botanical composition evaluation of the prairie from Cottam and Wilson (1966) illustrates the increase in big bluestem, little bluestem, Indiangrass, *Solidago* sp., *Eryngium* sp., *Lactuca* sp., tall gayfeather, *Ratibida* sp., and *Silphium* sp. (table 4). Quackgrass and Kentucky bluegrass were still declining as of 1961. Wild parsnip (*Pastinace sativa*), a troublesome weedy species, is also declining (R. Anderson 1972).

Table 4.--*Frequency of plant species in Curtis Prairie, Stand A, 1951 and 1961*[1]

	Frequency	
	1951	1961
	Percent	
Prairie species		
Achillea millefolium	44	55
Ambrosia artemisiifolia	79	53
Andropogon gerardi	6	44
Andropogon scoparius	--	47
Aslepias verticillata	59	61
Eryngium yuccifolium	1	69
Helianthus grosseseratus	--	5
Lactuca canadensis	48	84
Liatris aspera	2	37
Monarda fistulosa	53	73
Ratibida pinnata	6	32
Rudbeckia hirta	--	3
Silphium terebinthinacium	2	21
Solidago gigantea	--	3
Solidago nemoralis	--	81
Solidago rigida	--	8
Sorghastrum nutans	--	68
Other species		
Agrostis alba	--	8
Aster pilosus	71	31
Pastinaca sativa	32	11
Poa compressa	79	97
Solidago altissima	32	48
Weeds		
Agropyron repens	29	11
Oxalis stricta	54	44
Poa pratensis	60	13
Trifolium repens	74	43

[1]Data from Cottam and Wilson (1966).

Hadley (1970) reported an increase in big bluestem and little bluestem, and a decrease in Kentucky bluegrass following one spring burn in eastern North Dakota. Other species that increased were prairie dropseed, prairie cordgrass, saltgrass (*Distichlis stricta*), western snowberry, and Arkansas rose. Wheatgrass increased on upland sites but declined on lowland sites. Those species that declined were porcupine grass, needle-and-thread, *Poa* sp., *Muhlenbergia* sp., foxtail barley, prairie clover, and heath aster. All of these data were based on yields taken in 1966, a drier than normal year (Hadley 1970). Total herbage yield was 2,980 lb/acre (3,348 kg/ha) on the unburned plot and 3,833 lb/acre (4,307 kg/ha) on the burned plot.

Total production of herbage on the Curtis Prairie in Wisconsin 1 year after burning was 8,478 lb/acre (9,526 kg/ha) compared to 4,180 lb/acre (4,697 kg/ha) on the unburned site (R. Anderson 1972). Similar differences for the same prairie have been shown by Peet and others (1975). Removal of litter, and increased soil temperatures and daylight in early spring were the main factors contributing to the increased plant growth.

Scrub oak (*Quercus ellipoidalis*) is very abundant in Wisconsin prairies that had been protected from fire for 25 to 80 years (Vogl 1967).

FIRE EFFECTS - FESCUE PRAIRIE

The complexity of fire effects on fescue prairie does not allow a simple assessment of relative detriment and benefits in the Rocky Mountain foothills and the plains area of the aspen parkland (Bailey 1978). Prescribed burning research is very recent and much is still unpublished. Wildfires reduced forage production, plant vigor, basal area, leaf length, and number of flowering culms in the rough fescue - Parry's oatgrass community in the foothills of southwestern Alberta (Johnston, Range Scientist, Agric. Res. Stn., Lethbridge, Alberta, personal communication). A mid-April 1976 prescribed burn, prior to growth of rough fescue, maintained forage production, reduced basal area, leaf length, and number of flowering culms in the first year when growing season precipitation was normal (Klumph, Range Management Specialist, Energy and Nat. Res., Lethbridge, Alberta, personal communication). The second year, when precipitation was below normal, forage production was significantly higher on burned areas than on unburned areas.

A July wildfire near Missoula, Mont., decreased cover and frequency of bluebunch wheatgrass and Idaho fescue, but cover and frequency of rough fescue was maintained (Mitchell 1958).

The foothill ecotypes of rough fescue were 2 to 3 ft (0.6 to 0.9 m) tall and have 8- to 20-inch (20- to 51-cm) diameter bunches (Moss and Campbell 1947). Response of the big bunches to burning depends upon severity of the fire. Mitchell (1958) observed a tall stubble on the burned rough fescue clumps. This stubble insulated the crown from an excessive rise in temperature during burning. He attributed the cause of the maintenance of rough fescue and decline in Idaho fescue and bluebunch wheatgrass under burning to differences in crown characteristics. The fire burned closer to the crown of Idaho fescue and bluebunch wheatgrass.

Not all fires burn the foothill ecotypes of rough fescue in the same manner as reported by Mitchell (1958). Wright (1971) found that a bunchgrass with high density of fine fuels maintained the heat longer within the clump than did one with coarse culms and a lower density of fine fuels. Under certain conditions, severe damage and high mortality can be inflicted upon a big bunchgrass like rough fescue. The fire may burn down into the crowns of rough fescue clumps under very dry conditions. A backfire, a slow-moving headfire, or continued burning of clumps after the fire front passes may generate hot fires within plants resulting in a high mortality. Apparently,

Idaho fescue's growth form is more susceptible to continuous burning after the passage of a flame front than is rough fescue or bluebunch wheatgrass (Wright and Britton 1976). The latter two grasses develop larger bunches, coarser stems, and less fine fuel close to the growing point than does Idaho fescue. According to Conrad and Poulton (1966), a hot July wildfire in northeastern Oregon killed many more Idaho fescue plants than bluebunch wheatgrass plants.

A complex relationship exists between prescribed fire and rough fescue-western porcupine grass communities on the plains of central Alberta (Bailey and Anderson 1978). The first growing season after early spring or late fall burning, total herbage yields were the same as the unburned control [1,050 to 1,215 lb/acre (1,180 to 1 365 kg/ha)]. However, there were significant changes in plant composition (table 5). Spring burning reduced foliar cover 22 percent and seed production of rough fescue 97 percent; but fall burning was detrimental to western porcupine grass, particularly number of seed heads (reduced 97 percent). Cool season plants such as sedge and Hooker's oatgrass were reduced by spring fire. Fire usually increased cover and frequency of most forbs. The half-shrub, fringed sage, was reduced by both fires.

Table 5.--*Canopy coverage (percent) and plant frequency (percent) in fescue grassland following prescribed burning (data from M. Anderson 1972; Bailey and Anderson 1978)*

Species	Unburned		Burned			
			Fall		Spring	
	Cover	Frequency	Cover	Frequency	Cover	Frequency
Rough fescue	[1]84a	100	79b	100	62c	100
Western porcupine grass	86a	100	79b	100	84a	100
Hooker oatgrass	18a	56	6b	52	1b	68
Sedge	54a	100	55a	100	44b	100
Bearded wheatgrass	6	31	4	34	8	57
Milk vetch	4	32	12	77	11	60
Three-flowered avens	1b	7	11a	62	10a	58
Smooth aster	1	13	3	46	6	55
Western yarrow	1b	15	2a	24	4a	50
Prairie crocus	7	59	7	61	8	57
Pasture sage	3a	26	<0.5b	3	<0.5b	2

[1]Values within a row followed by the same letter are not significatly (P <0.05) different.

Another year, when spring growth was initiated earlier and burning was conducted when rough fescue leaves were about 4 inches (10 cm) tall, rough fescue, bearded wheatgrass, and slender wheatgrass cover was reduced by 60 percent the first growing season. It took 3 years for the species to recover. Perennial forbs more than doubled, particularly milk vetch (*Astragalus striatus, A. flexusus*), three-flowered avens (*Geum triflorum*), and western yarrow.

In a related study, M. Anderson and Bailey (1979) burned dense colonies of western snowberry that grow in patches on the grasslands. One year after spring burning, there was increased cover of perennial forbs, including American vetch, vetchling (*Lathyrus ochroleucus, L. venosus*), woundwort (*Stachys palustris* var. *pilosa*), northern bedstraw, and herbaceous sage. An annual forb, Russian pigweed (*Axyris amaranthoides*), grew only in burned areas the first year after burning and decreased during the second and third years.

Shrubs responded the same to fire whether they were burned in the spring or fall (Bailey and Anderson 1978). Silverberry and fringed sage were seriously harmed. Rose and western snowberry were moderately harmed (M. Anderson and Bailey 1979; Bailey and Anderson 1978). Herbaceous sage and raspberry (*Rubus strigosus*) increased dramatically.

Early spring burning in one area of central Alberta has been conducted annually over the past 25 to 30 years (H. Anderson and Bailey 1980). Preliminary results show that the frequency (percentage) of all shrubs--silverberry, rose, aspen, serviceberry, and chokecherry--is higher on the burned than on unburned plots. Frequency of western snowberry remained the same, and only prickly rose (*Rosa scidularis*) decreased. However, cover of all shrubs, except for herbaceous sage, was reduced 83 percent by annual burning. The high frequency yet low cover of shrubs seems to be indicative of a fire environment for tenacious shrubs.

Grasses and forbs that increased under the long-term burning program included prairie sandreed, sedge (*Carex obtusata, C. heliophila*), Missouri goldenrod, buffalobean, western yarrow, and bedstraw. Rough fescue and western porcupine grass decreased.

Based on present knowledge, fire apparently has the potential to remove litter buildup on ungrazed fescue grassland and to control shrubs with only moderate damage to the grasses. Forage losses can be minimized by using fire only during those springs that are preceded by above-normal precipitation. The desired interval for use of fire to control shrubs is probably 5 to 10 years. More judicious use of these ranges by cattle, sheep, and game in combination with burning may enhance the healthiness of these grasslands.

BENEFICIAL EFFECTS OF FIRE IN PRAIRIE GRASSLANDS

Where fire is an appropriate management tool, the major benefits of prescribed burning in grasslands are to control undesirable shrubs and trees, burn dead debris, increase herbage yields, increase utilization of coarse grasses, increase availability of forage, improve wildlife habitat (more food with unburned patches for cover), and to control cool season species where warm season grasses are dominant (Wright 1974a). Several objectives can be achieved simultaneously with one burn, the major advantage of using fire as a management tool.

When large amounts of litter cause stagnation, in the tallgrass and southern mixed prairie grasslands, fire is an effective tool for increasing plant growth (Weaver and Rowland 1952; Kucera and Ehrenreich 1962; Peet and others 1975; Sharrow and Wright 1977a). Removal of the litter permits soil temperatures to rise 10° to 30°F (6° to 17°C) in early spring (Peet and others 1975), which stimulates nitrification by bacteria (Sharrow and Wright 1977a). The high population of soil bacteria after fire (Neuenschwander 1976) decomposes organic matter to produce additional nitrates. This sequence of events, plus optimum growing temperatures created by the bare soil, allows warm season plants to grow at an optimum rate if moisture is adequate (Sharrow and Wright 1977a, 1977b). Thus, most of the fertilizing effect after a fire comes from nitrates released when bacteria consume organic matter, not from nutrients in ash (Old 1969; Sharrow and Wright 1977a).

The young, tender growth after fire is naturally more palatable and easily accessible to livestock and wildlife. It enables us to use fire effectively to attract livestock to grasses that are normally too coarse and contain too much litter to be palatable. Undesirable cool season grasses and forbs can be reduced with spring burns. Forbs, which provide an important food source for many upland game birds, are frequently more readily available on burned areas (Kirsch and Kruse 1972). Resprouts of shrubs are not only more accessible but may be more nutritious up to 3 years after the burn.

Controlling shrubs in the mixed prairie, tallgrass prairie, and fescue prairie is a major objective for using fire. Fire can be used to top-kill mesquite, completely kill 25 percent of the mesquite on upland sites, kill 50 percent to 80 percent of all cactus species, and kill Ashe juniper (Britton and Wright 1971; Wink and Wright 1973; Wright and others 1976a; Bunting and others 1979). Bragg and Hulbert (1976) have shown conclusive evidence that without fire the tallgrass prairie is easily invaded by shrubs and trees. Preliminary findings on an area burned for 25 consecutive years in central Alberta indicate that fire can be used to reduce cover of shrubs and trees (H. Anderson and Bailey 1980).

In the shortgrass prairie and semi-arid northern mixed prairie [less than 13 to 15 inches (33 to 38 cm) of annual precipitation], the use of fire does not appear to produce major beneficial effects, except in very special situations where it is desirable to control shrubs, improve livestock distribution, or remove litter that has stagnated plant growth.

POTENTIAL IMPACTS OF FIRE IN PRAIRIE GRASSLANDS

Detrimental effects of fire are generally associated with its misapplication. For example, if burning is conducted during dry years from fall to early spring under wildfire conditions, desirable herbaceous species are seriously harmed and have less than normal herbage yields for at least 2 years. This is especially true in the shortgrass and arid portions of the mixed prairie. In the northern Great Plains, more cool season species such as *Stipa* sp. and *Agropyron* sp. are encountered. These species may be harmed for 2 to 5 years, depending upon season of burn and whether the plants are under moisture stress.

Nevertheless, dry years are often best for long-term effectiveness in killing some shrubs when there are minimum amounts of fine fuel. Eliminating juniper species is a good example. Fire may be needed only every 20 to 30 years to control juniper, and burning during droughts can be tolerated if the ranges are rested from grazing until herbaceous species have fully recovered.

Erosion following fires is not likely to be a serious problem unless the slopes are steeper than 20 percent (Wright and others 1976b) or the soils are sandy. Sandy soils are subject to wind erosion when protective plant cover is removed. If burning is considered desirable on such soils, low-intensity fires should be used and burning planned so that a mosaic of unburned areas remains.

Smoke can be objectionable near highways and populated areas. Burning should be done when there is a steep adiabatic lapse rate (daytime) so that the smoke will rise and disperse at high altitudes. Burning should be done when winds are blowing away from nearby towns. Nighttime burning is particularly undesirable because smoke will drift and settle in low-lying valleys and stay there until the middle of the next day. These situations can lead to complaints to pollution boards and cause further restrictions on burning. Such incidents can be avoided by burning within the prescribed burning regulations and by burning as rapidly as possible. Most people will tolerate smoke for a few hours, but not for several days.

Fire should not be used more frequently than every 5 to 10 years in the western and central portions of the Great Plains. Long-term declines in production of grasses as a result of burning more frequently have been documented (Neuenschwander 1976). As one goes eastward and the precipitation increases, fire frequency may be every 1 to 3 years without harming the grasses (Anderson and others 1970).

MANAGEMENT IMPLICATIONS

Shortgrass Prairie

Fire has few uses in the shortgrass prairie. The grasses do not benefit from burning. They tolerate fire without loss in forage during wet years (Trlica and Schuster 1969; Heirman and Wright 1973; Wright 1974b), but are moderately to severely harmed for 2 to 3 years when precipitation is below normal (Hopkins and others 1948; Launchbaugh 1964; Dwyer and Pieper 1967). Nevertheless, prescribed burns can be used to clean up chained debris and kill pricklypear and other *Opuntia* species less than 2 ft (0.6 m) tall (Heirman and Wright 1973). In eastern New Mexico prescribed fires can be used to control small juniper trees (Dwyer and Pieper 1967). Fire also will increase herbage production on sand shinnery oak range in good condition (McIlvain and Armstrong 1968).

Mixed Prairie

CENTRAL AND SOUTHERN GREAT PLAINS

Prescribed fire has a wide variety of uses in the mixed prairie. Fire is especially useful in the southern and central portions to increase production and palatability of coarse grasses such as tobosagrass and little bluestem that have a tendency to accumulate litter. Most grasses tolerate fire well during years with normal to above-normal precipitation, exceptions being sideoats grama and Texas wintergrass (Wright 1974b). Cool-season annuals such as little barley and Carolina canarygrass are also severely harmed. Spring fires kill many undesirable forbs--i.e., annual broomweed--and cool-season annuals, minimizing competition for the warm-season perennials. Thus the warmer soil increases nitrates and reduces competition from "weeds," which provides an ideal environment for growth of warm season grasses if soil moisture is adequate. Fire can be used in the southern mixed prairie on a 5- to 8-year frequency (Sharrow and Wright 1977b).

Fire is effective for burning standing dead honey mesquite stems (Britton and Wright 1971) and killing some honey mesquite (Wright and others 1976a). Green honey mesquite trees are difficult to kill. Fire may also be used to kill 50 to 80 percent of the cactus (*Opuntia* sp.) (Bunting and others 1980), clean up chained debris (Wright 1972a), remove dead piles of Ashe juniper, kill young Ashe juniper trees (Wink and Wright 1973), remove brush to ease handling of livestock, and in some cases, improve wildlife habitat.

Generally, pastures should be burned on a manageable unit basis, unless tobosagrass is dominant. About 10 to 20 percent of each tobosagrass pasture should be burned each year on a rotational basis. Cattle should be grazing the burned area 2 to 3 weeks after a fire in spring and fall, taking the pressure off other grasses. Animals will not graze burned tobosagrass in summer or winter. It is desirable, therefore, to have both burned and unburned areas in tobosagrass pastures.

NORTHERN GREAT PLAINS

In the northern mixed prairie, information for the semi-arid areas [10 to 15 inches (25 to 38 cm) annual precipiation] indicates there may be only a limited place for fire as a management tool. However, fire is capable of killing silver sagebrush, fringed sage, Japanese bromegrass, and little club moss. More data are needed on the desired frequency of burning. Prescribed burning should probably be conducted in this region only following winters with above-average precipitation. Fall burning appears to have the most promise for not injuring desirable forage species (Clarke and others 1943).

In the more mesic areas [16 to 20 inches (41 to 51 cm) annual precipitation] of the northern mixed prairie, cool-season grasses (except for slender wheatgrass and smooth bromegrass) were more tolerant of fire than in the semi-arid mixed prairie. The warm-season grasses (little bluestem and big bluestem) benefit from burning (Kirsch and Kruse 1972). Shrubs (i.e., *Symphoricarpos occidentalis*) can be set back by fire (M. Anderson and Bailey 1979) and ponderosa pine seedlings can be killed (Gartner and Thompson 1972).

Periodic prescribed burning in fescue grassland will improve cattle distribution by removing litter on ungrazed slopes. Because shrubs are only set back by one burn, reburns or herbicide treatments are required to keep them in check. The effect of fire on wildlife is unknown. Prescribed burning probably should be done only during normal or wet years. Not enough research has been done to establish a reasonable estimate of burning frequency.

Tallgrass Prairie

The primary reasons for burning in the tallgrass prairie are to increase production and palatibility, improve nutritional value of tallgrasses, suppress encroachment of trees and shrubs, and reduce competition from undesirable cool season plants such as Kentucky bluegrass and smooth bromegrass. Annual burns do not appear to harm the native warm-season species if burned in late spring (Anderson and others 1970). Less frequent burns benefit all of the major tallgrass species--big bluestem, little bluestem, Indiangrass, and switchgrass--(Hensel 1923; Aldous 1934; Dix and Butler 1954; Robocker and Miller 1955; Kucera and Ehrenreich 1962; Hadley and Kieckhefer 1963; McMurphy and Anderson 1965; Hulbert 1969).

Exotic cool-season grasses are severely harmed by spring burning. Many researchers (Hensel 1923; Enrenreich 1959; Hadley and Kieckhefer 1963; Old 1969) have found that Kentucky bluegrass decreases 80 percent or more following a spring burn. Curtis and Partch (1950) found that Canada bluegrass and Kentucky bluegrass were severely damaged by spring burning. Similarly, Canada wildrye, Virginia wildrye (Robocker and Miller 1955), Japanese brome (McMurphy and Anderson 1965), and smooth bromegrass (Old 1969) are moderately damaged by fire. Species such as smooth bromegrass, which begins growth about mid-May, are only inhibited by burning, whereas species such as Kentucky bluegrass are almost eliminated by burning because they begin growth in early April (Old 1969).

Late spring (May 1) burning reduces all forbs (McMurphy and Anderson 1965), although the composition of forbs is changed relatively little (Anderson 1965). Kucera (1970) proposed a 3-year interval between burning to maintain dominance of warm season grasses, as well as to retain species diversity typical of the native prairie community.

Woody plants will invade a prairie protected from disturbances such as fire (Kucera 1960; Penfound 1964; Vogl 1967; Blan 1970; Bragg and Hulbert 1976). Thus, it seems reasonable that fire should be an effective tool to control woody plants. Although research results are limited, it appears that fire properly used will control woody plants. Annual burning during May controlled coralberry in Kansas (McMurphy and Anderson 1965). Pelton (1953) felt that periodic burning would favor western snowberry in Minnesota, but that annual burning would harm it.

PRESCRIBED BURNING GUIDES

General Comments

One cannot learn how to ride a bicycle by just reading printed instructions. One must get on the bicycle and practice. However, once the basics of riding a bike have been learned, the novice rider can read or listen to more experienced riders in order to improve his riding, increase efficiency of effort, safety, speed, ease, comfort, and satisifcation. The same is true for learning how to conduct prescribed burns.

There is a lot of art to prescribed burning. There are also many unforeseen circumstances peculiar to each burn. Nevertheless, experience is the best teacher. We learn by doing, and by doing, we learn rapidly. A wildfire can be frightening, but prescribed burning is not as dangerous as wildfire. Prescribed burning is dangerous to the inexperienced. It is very dangerous to those not fully experienced, for these are the persons who become overconfident and may have fires get away.

Models for prescriptions can be helpful in the planning phases of a burn, but they do not protect you against the intangibles--a hill on the side of a pasture that might cause unusual winds, a canyon on the lee side that may aid the formation of an intense firewhirl that will throw firebrands at greater distances than normal, unusual fuel densities that can create intense firewhirls, possibility of a nighttime low-level jet of wind, or volatile fuel material. Most people who conduct rangeland burns consider most fire danger index models to be too complicated and too time consuming to be useful. They usually use two to four critical variables to make a decision as to whether to burn.

The secret to all prescribed burning is to let the weather work for you. When all environmental factors are right, the job is easy. However, if the relative humidity is below 20 percent, if you are depending on a low pressure trough in late afternoon for your wind direction, if air temperature is above 80°F (27°C), or if average windspeeds are above 15 mi/h (24 km/h), prescribed burning can be a miserable job. On the other hand, do not be too cautious. Set a fire that will accomplish your objectives. The prescription that we like for most headfires is a relative humidity of 25 to 40 percent, air temperature 70° to 75°F (21° to 24°C), and wind 8 to 15 m/h (13 to 24 km/h). For backfires, you can burn under considerably cooler conditions, depending on amount of fine fuel and fine fuel moisture levels.

In volatile fuels, most firebrands ignite on punky wood, a cow chip, or lodge in a crack of bark, wood, or tight clump of grass. Punky wood and cow chips are by far of the greatest concern. The best defense is high humidity and a wide fireline. For example, a glowing ember has rarely been seen to start a fire when the relative humidity was above 50 percent. Below a relative humidity of 25 percent, potential for spot fires is great. Therefore, to burn on the high side of the 25 to 40 percent range minimizes danger from firebrands. Consumption of dead material, particularly standing material, will be reduced considerably if you burn with a relative humidity above 40 percent.

Low windspeeds [below 6 mi/h (10 km/h)] also reduce the risk of glowing firebrands starting spot fires. Unless prescribed burning windspeeds are above 8 mi/h (13 km/h) in grasslands, woody material will not ignite easily and if ignited may go out. This is especially applicable to standing material.

Relative humidity is related to temperature, but we have had a tendency to rely more heavily on relative humidity than temperature. However, 67°F (19°C) seems to be a threshold value. Below this temperature we usually get incomplete burns of woody materials. Above 75°F (24°C) we must be very careful. We do not recommend burning when the air temperature is above 80°F (27°C).

Every fire is different and confidence grows as one gains experience in a fuel type. If inexperienced in a certain vegetative type, seek out the best information available. Write a fire plan and a prescription for the planned burn (Fischer 1978). Burn a small area and start when conditions favor control--45 to 60 percent relative humidity, wind less than 6 mi/h, air temperature of 40° to 60°F (4° to 16°C). Burn in late afternoon or early evening when you know the relative humidity is on the rise. Experiment with a few small burns; learn something about fire behavior and the combustibility of various types of fuel. Document weather, amount of fine fuel, and fuel moisture for each burn.

Mixed Prairie with Honey Mesquite

(Low Volatile Fuel)

Detailed prescriptions for conducting burns in low volatile (mesquite-tobosagrass) and high volatile (Ashe juniper) fuels have been given by Wright (1974a). Depending on the objectives, a wide variety of prescriptions can be used and experience is always the best teacher. For example, if you want to clean up chained debris in buffalograss that has 2,000 lb/acre (2,247 kg/ha) of fine fuel, burn a 100-ft (30-m) wide fireline on the north and east sides when the relative humidity is 30 to 50 percent, wind is 5 to 10 mi/h (8 to 16 km/h), and air temperature is 60° to 75°F (16° to 24°C). Burn the rest of the pasture with a headfire when the relative humidity is 20 to 40 percent, wind is out of the southwest at 8 to 15 mi/h (13 to 24 km/h), and air temperature is 70° to 75°F (21° to 24°C).

If dead mesquite is standing and you wish to burn it, you need a minimum of 3,000 lb/acre (3,371 kg/ha) of fine fuel, relative himidity below 40 percent, and wind in excess of 8 mi/h (13 km/h). Burn a 100-ft (30-m) wide fireline on the north and east sides when the relative humidity is 50 to 60 percent and the wind is less than 8 mi/h (13 km/h). Headfire the rest of the pasture with a southwest wind when the relative humidity is 25 to 40 percent, wind is 8 to 15 mi/h (13 to 24 km/h), and air temperature is 70° to 75°F (21° to 24°C) (fig. 16).

The primary dangers in burning grasslands come from tumbleweeds and firewhirls. Tumbleweeds will ignite and then tumble, leaving flames in their path. Firewhirls develop where wind shears occur, such as when a headfire runs into a backfire, or a fire goes up slope into a wind. We have seen several firewhirls develop when headfires met backfires while winds were 10 to 15 mi/h (16 to 24 km/h). We have also seen two huge firewhirls develop when winds were light and variable. For these reasons, we prefer to burn with a steady wind and never burn into backfires, unless we have at least a 300-ft (91-m) fireline. Burning should be done with ridges, not across them.

Mixed Prairie with Juniper

(High Volatile Fuel)

Firebrands are a serious problem when burning chained or piled dead juniper. Thus, for safety, we need to burn out a 400-ft (122-m) fireline on the north and east sides of a pasture (fig. 17). Burn out the dead piles of brush when the grass is green (May to early June), the wind is less than 10 mi/h (16 km/h), and the relative humidity is above 45 percent. Later (January and Fegruary), burn out the bluestem grass in the firelines when the relative humidity is 50 to 60 percent and the wind is less than 8 mi/h (13 km/h). Nonflaming firebrands are rarely a problem when the relative humidity is above 50 percent (Bunting and Wright 1974). Where buffalograss occurs, more wind and less humidity are required.

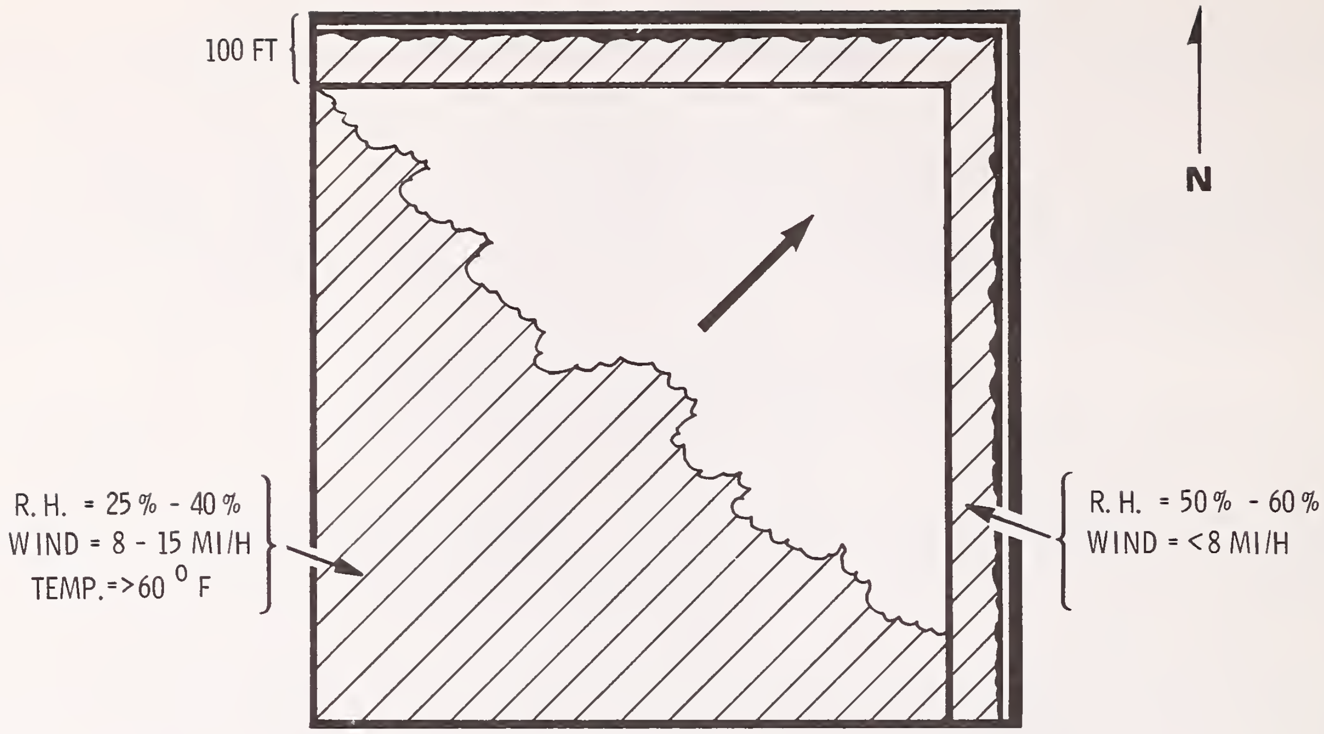

Figure 16.--Fire plan for fuels of low volatility. After firelines are cut, a 100-ft (30-m) strip on the downwind sides (north and east) of a pasture is backfired with winds less than 8 mi/h (13 km/h) and with relative humidities between 50 and 60 percent. Then the pasture is headfire with the prevailing wind (southwest) averaging from 8 to 15 mi/h (13 to 24 km/h) and relative humidities from 25 to 40 percent.

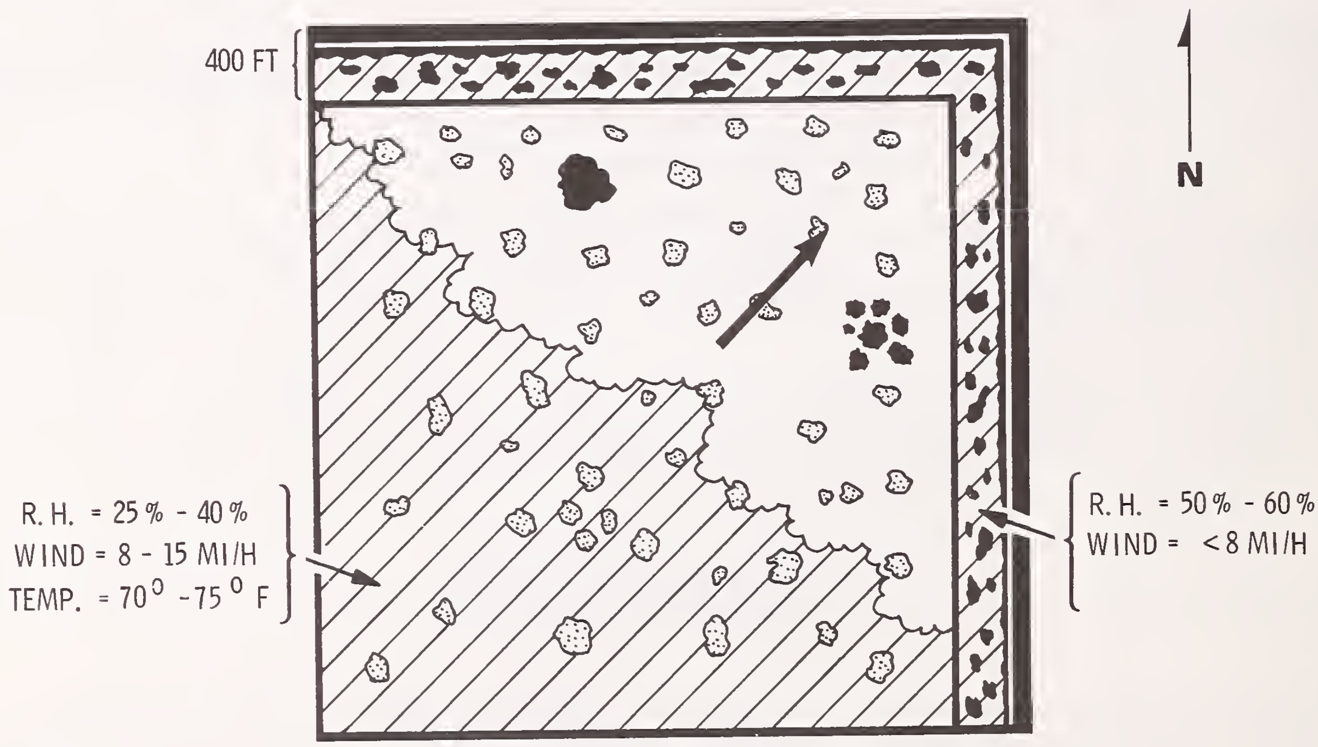

Figure 17.--Fire plan for fuels of high volatility. When the grass is green, juniper piles in the 400-ft (122-m) strip (black splotches) on the downwind sides (north and east) are burned with wind velocities less than 10 mi/h (13 km/h) and relative humidity above 45 percent. Eight months later (when grass is dormant), the grass in the 400-ft (122-m) strip is burned when the wind is less than 8 mi/h (13 km/h) and relative humidity is between 50 and 60 percent. Lower relative humidities may be used if the grass fuel is less than 2,000 lb/acre (2,247 kg/ha). All large concentrations of piles are backfire on the downwind sides of main area to be burned, and then the entire area is burned into the prepared firelines with a wind of 8 to 15 mi/h (12 to 24 km/h) and a relative humidity of 25 to 40 percent.

After the fireline is burned out, burn the rest of the area with a southwest wind when the relative humidity is 25 to 40 percent, wind is 8 to 15 mi/h (13 to 24 km/h), and air temperature is 65° to 75°F (18° to 24°C). After a rain, wait at least 5 days to burn.

For safety, avoid burning backfires into headfires and avoid burning across ridges. Firewhirls can easily develop in those situations. In highly volatile fuels such as juniper, burn into heavily grazed pastures, when possible, to minimize risk. In this fuel type, one should have at least two seasons of burning experience before assuming responsibility for conducting a burn.

To burn grasslands with young, green juniper trees [2 to 5 ft (0.6 to 1.5 m) tall], one can use much smaller firelines--about 50 ft (15 m). In these cases cut a 10-ft (3-m) fireline around the entire pasture. Then burn out 50 ft (15 m) on the lee sides in late evening or early morning and put the fire out on the windward side with a pumper.

Sand Shinnery Oak with Little Bluestem

(Moderately Volatile)

Burning techniques for this type in Oklahoma have not been documented. Generally there is enough grass to permit a backfire to burn back through the shinnery under cool conditions [i.e., relative humidity 50 to 60 percent, air temperature 60°F (16°C), and wind 5 to 10 mi/h (8 to 16 km/h)]. In many cases the fire will go out as it backs up. After a 200- to 300-ft (61- to 91-m) fireline has been burned, then the area can be headfired.

Refinement of technique is needed in this fuel type. Oak leaves act as firebrands, so one must be reasonably careful. However, based on our experience, we have never had trouble with oak leaves starting spot fires beyond 66 ft (20 m). We suspect that a 200-ft (61-m) fireline would be adequate for headfires when the relative humidity is 25 to 40 percent, wind is 5 to 10 mi/h (8 to 16 km/h), and air temperature is 70° to 75°F (21° to 24°C). With 2,000 to 4,000 lb/acre (2,247 to 4,494 kg/ha) of fine fuel, cooler conditions would give satisfactory burns. Based on volatile fuel data, the firelines should be burned when the relative humidity is above 50 percent, wind less than 8 mi/h (13 km/h), and air temperature is 45° to 65°F (7° to 18°C). The high humidity would be especially important to minimize danger from firebrands.

Firelines should be cut around the area to be burned, but the inside of the 200-ft (61-m) strips could be natural breaks. Often the fire will go out when backing up, and a pumper could be used to put out the spots that continue to burn.

Tallgrass Prairie

In the tallgrass prairie, particularly the Flint Hills region, many ranchers have burned for years and know how to do it. Launchbaugh and Owensby (1978) have written a bulletin that contains prescription burning guidelines for the State of Kansas. The authors state that firebrands are not a problem, except for some areas with eastern red-cedar. Humidity in this area is usually 50 to 60 percent, so burning is relatively safe. Fine fuel is continuous and may be as much as 3,000 to 4,000 lb/acre (3,371 to 4,494 kg/ha).

Launchbaugh and Owensby begin burning on the leeward sides of a pasture and let the fire back into the pasture. Two spray rigs patrol and lay down a wet line when necessary. Usually, the authors can backfire from a trail or road. They rarely plow permanent firelines. After the fire has backed up 100 to 150 ft (30 to 46 m), they

headfire the rest of the pasture. Headfires are set with 5 to 10 mi/h winds (8 to 16 km/h) if improvement of forage quality is the only concern. Where brush control is important, the authors recommend burning in winds from 5 to 15 mi/h (8 to 24 km/h) and when relative humidity is about 40 percent. Ambient temperature is not important, but generally varies from 60° to 75°F (16° to 24°C).

Where tall eastern redcedar (fig. 18) is to be burned, Launchbaugh and Owensby usually rest the pasture to be assured of 3,000 to 4,000 lb/acre (3,371 to 4,494 kg/ha) of fine fuel. Then they burn out a 100- to 200-ft (30- to 61-m) fireline late in the evening or early in the morning when dew is on the grass. After the fireline has been burned, the authors set a headfire, with winds up to 15 mi/h (24 km/h) and low humidity (40 percent or so). Coralberry has not produced troublesome firebrands, so no special preparations are needed when this shrub is present.

Figure 18.--Fire can be used in the tallgrass prairie to control redcedar. Trees less than 4 ft (1.22 m) tall are easily controlled with fire. To kill trees taller than 4 ft (1.22 m), one must have at least 2,000 lb/acre (2,247 kg/ha) of grass and burn with 10 to 15 mi/h (16 to 24 km/h) winds.

Marsh Burns

Marshes are usually burned to reduce the density of reeds, create new feeding areas, and to create more edge effect for nesting areas. In the north-central Nebraska Sandhills, Schlichtemeier (1967) found that thick, dense stands of marsh could easily be burned. Excellent results were achieved after ice was 9 to 12 inches (23 to 30 cm) thick and 2 to 4 inches (5 to 10 cm) of snow covered the surrounding range. Four burns were conducted in January and February under the conditions shown in table 6. Combustibility of vegetation varied only slightly on all four burns. Density of reed (*Phragmites communis*) and bulrush (*Scirpus* sp.) decreased 85 to 60 percent. Schlichtemeier (1967) burned successfully in freezing weather, because marshes have large quantities of dry material in thick layers partially protected from the weather. Light or moderate grass fuels will not burn under similar conditions.

Table 6.--*Prescriptions for four burns in a reed marsh in north-central Nebraska*[1]

Burn no.	Relative humidity	Temperature		Wind	
	Percent	°*F*	°*C*	*Mi/h*	*Km/h*
1	72	30	-1	15	24
2	60	37	3	7	11
3	67	17	-8	23	37
4	52	42	6	17	27

[1]Data from Schlichtemeier (1967).

Fescue Prairie and Aspen Parkland

(Low to Highly Volatile Fuels)

Western snowberry, willows, and dead aspen are volatile fuels and produce abundant firebrands. Firebrands ignite dung piles, which cause spot fires, most frequently when the relative humidity is below 25 percent. Consequently, grasslands that have few shrubs or trees are usually comparatively safe to burn.

Snow is an advantage to spring burning in mesic areas of the northern Great Plains. Grasslands melt free from snow several weeks before adjacent shrublands and forest. Grasslands can then be burned a few days after snowmelt, with the wet forest and shrublands or a plowed line 12 to 14 ft (3.7 to 4.3 m) wide acting as a fireline. Several weeks later the green grassland is an effective fireline when the shrubland and forest are burned.

The weather conditions required for safe burning in the Alberta aspen parkland are presented in table 7. The aspen forest and snowberry shrublands have been successfully burned only with headfires. The prescription for grass fires will need to be altered as fine fuel decreases. For example, if you were to burn grazed rough fescue, the relative humidity may need to be as low as 25 to 40 percent, wind 8 to 12 mi/h (13 to 19 km/h), and air temperature 50° to 70°F (10° to 21°C). A few small test burns will help one determine the desired range of weather conditions.

Dung piles are the major cause of spot fires. Firebrands from woody plants land in the cracks of dung piles. Dung piles exposed to bright sunshine and low humidity may smolder for hours and then ignite adjacent fine fuels. Horse dung is particularly dangerous because it is round. As it burns, it becomes lighter and may roll in the wind, igniting fine fuels as it travels.

Table 7.--*Weather conditions required for successful spring burning in the central Alberta aspen parkland*

Vegetative type	Minimum temperature		Wind		Maximum relative humidity	Drying time
	°F	°C	Mi/h	Km/h	Percent	Days
Fescue grassland	45	7	2-12	3-19	65	1
Snowberry shrubland	55	13	2-12	3-19	50	4
Aspen forest[1]	59	15	4-12	6-19	40	10
Aspen forest[2]	64	18	8-16	13-26	30	14

[1]Few spot fires, but only 25 to 50 percent of the forest will burn when relative humidity is 30 to 40 percent.

[2]Spot fires will be numerous, requiring a 400-ft (122-m) fireline downwind, but 80 to 100 percent of the forest will burn when relative humidity is 10 to 30 percent.

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APPENDIX--SUMMARY OF FIRE EFFECTS DATA

Shortgrass Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Grasses	Buffalograss Blue grama	Decreased for 2 to 3 yr after burning during drought yr; buffalograss and blue grama not harmed when winter and spring precipitation are above normal.	
	Red threeawn	Generally decreased by fire.	
	Sand dropseed	Generally decreased by fire.	But tolerant when winter and spring precipitation were 40 percent above normal.
	Galleta Ring muhly Slim-stemmed muhly Wolftail	Generally decreased by fire.	Based on data from wildfire during a below average precipitation year.
	Little bluestem	Production decreased after burn.	Based on data from sand shinnery oak areas in Oklahoma.
	Tumble windmill grass	Not harmed by fire.	
	Sand bluestem	Production increased after burn.	Based on data from sand shinnery oak areas in Oklahoma.
	Switchgrass	Production increased after burn.	
	Weeping lovegrass	Not harmed by fire.	
Forbs	Annual broomweed Horsetail conyza Silverleaf nightshade Western ragweed	Harmed by spring burning.	Generally, forbs are harmed more by spring burns than fall burns.
	Multistem evax Warty euphorbia Woolly plantago	Not affected by spring burning.	
	False mesquite	Favored by spring burning.	

SOUTHERN GREAT PLAINS

Shortgrass Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Shrubs	Mesquite	Fire tolerant.	Exceptional sprouters, especially on the High Plains. Seedlings are reasonably tolerant of fire when more than 1 yr old. A February burn reportedly killed 31 percent of seedlings less than 1 yr old. Repeated burns will keep mesquite in check.
	Shinnery oak	Fire tolerant.	Increased 15 percent following fire, but produced no acorns during year of burn.
	Algerita Aromatic sumac Chickasaw plum Fourwing saltbush Skunkbush sumac Winterfat	Fire tolerant sprouters.	Fourwing saltbush is palatable and is fully recovered 3 yr after being burned.
	Sand sage	Fire tolerant sprouter.	Resprouts after fire and produces abundant seedlings after burning.
	Cacti (*Opuntia*)	Fire intolerant.	50 to 80 percent of most species are killed, especially if they are less than 2 ft tall. Large clumps of prickly-pear or tall cholla usually survive fires.
		Mixed Prairie	
Grasses	Sideoats grama (rhizomatous form)	Harmed.	More tolerant in wet years - yield decreased 51 percent in dry years vs. 12 percent in wet years. Takes at least 3 yr to recover after being burned during dry years.
	Little bluestem	Tolerance is moisture dependent.	Decreases about 50 percent following burning in dry years, but will increase as much as 81 percent during wet years after a spring burn.
	Tobosagrass	Very tolerant.	Burning increases production twofold to threefold and palatability tenfold when precipitation is average or higher. When precipitation is below average, yields may be reduced 20 to 50 percent. Never burn more than one-fifth to one-eighth of a pasture each year.

SOUTHERN GREAT PLAINS

Mixed Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Grasses	Arizona cottontop Meadow dropseed Plains bristlegrass Texas cupgrass Vine mesquite	Tolerant.	Thrive after fire when moisture is adequate. Vine mesquite shows increased yields for 2 years; Arizona cottontop for 1 year.
	Tall grama	Intolerant.	Tolerates fire after burns in wet years; declines as much as 60 percent during dry years.
	Sideoats grama-bunchgrass form	Tolerant.	
	Texas wintergrass	Intolerant.	Severely harmed by broadcast fires, but favored by cool, creeping spring ground fires.
	Little barley Carolina canary grass	Intolerant of spring burning.	Cool season annual grasses.
Forbs	Annual broomweed Bitterweed Scarlet globemallow Wild onion	Intolerant.	
	Annual sunflower Carolina horsenettle Lambsquarter Silverleaf nightshade	Common on burns.	
	Plains dozedaisy Redseed plantain	Tolerant.	Second season after burning plains dozedaisy and redseed plantain reach maximum importance value.
	Perennial ragweed	Tolerant.	
	Goldenrod	Tolerant.	

SOUTHERN GREAT PLAINS

Mixed Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Trees & Shrubs	Mesquite	Tolerance dependent on age, stand history, weather, fire intensity.	Green mesquite tolerant except when very young. With temperatures greater than 260°C, plants up to 1.5 yr are easily killed; 2.5-yr-old plants are severely harmed; plants 3.5 yr and older are very tolerant. Trees previously top-killed (drought, herbicides, etc.) are moderately harmed--25 percent mortality on upland sites; none along river bottoms.
	Eastern redcedar	Intolerant.	Non-sprouter - leaves very flammable; bark very thin; seedlings abundant after fire.
	Ashe juniper	Intolerant.	Non-sprouter - leaves very flammable; bark very thin; seedlings abundant after fire. Amount of mortality depends on amount of fine fuel and fire intensity. Minimum of 700 to 1,000 lb/acre (786 to 1,124 kg/ha) of fine fuel needed to kill trees 2 to 4 ft (0.6 to 1.2 m) high. With 2,500 lb/acre (2,809 kg/ha) or more, all juniper trees will be killed.
	Redberry juniper	Tolerant when over 12 yr old.	Sprouter. Fire reduces "sphere of influence" - permits grasses and forbs to become established closer to trees.
	Lotebush	Tolerant; regrowth is slow until fourth year after burning.	Sprouter - regains prefire position in about 6 to 10 yr after fire.
	Fourwing saltbush	Very tolerant.	Palatable species, vigorous sprouter - fully recovered 3 yr after burn.
	Algerita) Little leaf sumac) Oak)	Tolerant.	Sprouters - little research data available.
	Smoothleaf sumac	Very tolerant.	Usually comes back on the hottest areas of a burn; vigorous sprouter.
	Cacti	Intolerant.	Frequently present in high densities in mesquite-tobosa communities. Easily killed by fire (50-80 percent mortality). Fire acts as agent to initiate interactions that result in mortality; e.g., insect activity, rodent activity, drought.

SOUTHERN GREAT PLAINS

Mixed Tallgrass-Forest

Growth form	*Species*	*Fire effects*	*Remarks*
Grass	Little bluestem	Tolerant.	No fire research has been done. There is current interest in using fire on a 4-yr rotation to keep oak sprouts suppressed in bluestem pastures. Considering this precipitation zone, and based on fire effects data from other areas, little bluestem should be very tolerant of fire.
Trees	Blackjack oak Post oak	Easily top-killed but resprout vigorously.	

CENTRAL GREAT PLAINS

Tallgrass Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Grasses	Canada bluegrass	Severely harmed.	Generally an 80 percent reduction. Cool season species.
	Kentucky bluegrass		
	Canada wildrye		
	Japanese brome	Harmed.	Smooth brome is more tolerant of early spring burns than other cool season species because it does not germinate until mid-May.
	Smooth brome		
	Virginia wildrye		
	Fall witchgrass	Favored.	
Forbs	Dotted gayfeather		
	False boneset		
	Missouri goldenrod	Tolerant.	Most species favored by fire, but some people have reported declines for prairie clover and goldenrod.
	Plains wild indigo		
	Prairie sunflower		
	Silky prairie clover		
	Goosefoot		
	Gromwell		
	Heath aster	Harmed.	
	Pepperweed		
	Pigweed		
	Prairie coneflower		
	Virginia day flower		
	Woolly plantain		
Shrubs	Missouri spurge	Unchanged.	
	Western ragweed		

CENTRAL GREAT PLAINS

Short Grass and Mixed Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Grasses	Buffalograss Blue grama Western wheatgrass	Allow 2 to 3 yr for recovery during dry years; not harmed when precipitation is above normal.	Buffalograss-blue grama mixture recovered 35, 62, and 97 percent following the first, second, and third growing seasons after being burned in the spring during a dry year. Western wheatgrass recovered 18, 27, and 77 percent, respectively, during the same growing seasons.
	Big bluestem Hairy grama Hairy sporobolus Little bluestem Sideoats grama	Harmed by fire during dry years.	No data for wet years, but would probably tolerate fire.
Forbs	See data for Southern Great Plains		

Tallgrass Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Grasses	Big bluestem Indiangrass Little bluestem Switchgrass	Very tolerant.	Production often doubles after burning, unless burned annually. If burned annually, burns should be conducted about May 1. Drought is rarely a problem in this rainfall belt.
	Blue grama Buffalograss Hairy grama Prairie junegrass Prairie sand dropseed Sideoats grama	Generally no change to a slight increase.	

NORTHERN GREAT PLAINS

Mixed Grass Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Grasses	Bearded wheatgrass Green needlegrass	Frequency reduced by spring burning.	
	Pennsylvania sedge Prairie sandreed	Frequency unchanged by spring burning, but harmed by late summer fires.	
	Blue grama *Carex eleocharis* Junegrass Muhlenbergia Needle-and-thread Threadleaf sedge Western wheatgrass	Frequency unchanged or increased by early spring burning.	Increase in frequency does not necessarily imply increase in herbage yield, which might be reduced for several years. Late spring burning harms western wheatgrass.
	Big bluestem Little bluestem	Probably not harmed by fire and could be burned during years with normal to above normal precipitation to control scrubby ponderosa pine and undesirable shrubs.	
Forbs	Silverleaf scurfpea Slim-flowered scurfpea	Increases and decreases have been reported following spring burning.	Frequencies of most forbs remained unchanged after spring burning.
	Leafy spurge Little club moss	Frequency reduced by fall burn.	Data taken 4 yr after a fall fire.
	Hairy golden aster Wild lettuce	Harmed by late summer fire.	
	Hedeoma hispida Stickseed	Increased after fall burning.	Data taken 4 yr after a fall fire.

NORTHERN GREAT PLAINS

Mixed Grass Prairie

Growth form	*Species*	*Fire effects*	*Remarks*
Shrubs	Arkansas rose Fringed sagebrush Silver sagebrush	Reduced by spring burning.	
	Herbaceous sage	Increased after spring burning.	
Tallgrass Prairie (True Prairie)			
Grasses	Big bluestem Blue grama Indiangrass Leiberg panicum Little bluestem Prairie cordgrass Prairie dropseed Prairie sandreed Saltgrass	Increase after spring burning.	Some of this information is based on frequency data and may or may not reflect yields. Eastern North Dakota study.
	Wheatgrasses	Increased on upland sites, but declined on lowland sites.	
	Bearded wheatgrass Canada bluegrass Foxtail barley Junegrass Kentucky bluegrass *Muhlenbergia* sp. Quackgrass Rushes Slender wheatgrass Smooth brome	Usually harmed by fire, but some data show no change and some show an increase.	

NORTHERN GREAT PLAINS

Tallgrass Prairie (True Prairie)

Growth form	*Species*	*Fire effects*	*Remarks*
Forbs	Erigeron Goldenrod Common ragweed Rattlesnake master	Increase after spring burning.	See table 3 of text for other forbs that increase after burning.
	Atlantic wild indigo	No change.	
	Heath aster	Variable responses.	Declined in eastern North Dakota, but increased with spring burning in Wisconsin.
	Canada thistle *Oxalis stricta* Prairie clover Purple coneflower *Trifolium repens* Wild parsnip	Declined after spring burning.	
Shrubs & Trees	Arkansas rose Western snowberry	Increase after spring burning.	
	Scrub oak	Increases with fire exclusion.	

FESCUE GRASSLANDS

Growth form	*Species*	*Fire effects*	*Remarks*
Grasses	Agropyron-type communities Blue grama - Needle-and-thread communities	Reduced yields up to 50 percent following spring burning during a dry year. Effects of fall burning less pronounced - production decreased by 30% first year with recovery second year.	Agropyron-type communities are more sensitive to spring burning than blue grama and needle-and-thread.
	Bearded wheatgrass Slender wheatgrass Western porcupine grass	No change in cover after spring burn with good moisture; fall burns harmful.	Fall burning severely harmed the wheatgrasses. Western porcupine grass was reduced 25 to 30 percent by fall burns.
	Prairie sandreed Sedge	Increased with annual spring burn.	
	Hooker's oatgrass Parry oatgrass Rough fescue Sedge Timothy	Harmed by spring burning.	Rough fescue required 3 yr for full recovery. It tolerates fall burns better than spring burns.
Forbs	Bedstraw Buffalobean Milk vetch Missouri goldenrod Stickseed Three-flowered avens Western yarrow Woundwort	Increased after spring and/or fall burning.	
	Little club moss	Seriously harmed by spring and fall burns.	
Shrubs	Fringed sage Silverberry Silver sagebrush	Seriously harmed by spring and fall burns.	
	Arkansas rose Prickly rose Western snowberry	Moderately harmed.	Desired frequency for shrub control is probably 5 to 10 yr. Forage losses can be minimized by using fire only during those springs preceded by normal to above normal precipitation.
	Herbaceous sage Raspberry	Increased dramatically.	

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Presents basic ecological data and summarizes current knowledge about the effect of fire on vegetation in the Great Plains. Shortgrass, mixed grass, and tallgrass prairies are discussed in the southern, central, and northern Great Plains. Describes each geographic area, its vegetation, and the effects of fire. Includes sections on fire history, beneficial effects of fire, potential impacts, management implications, prescribed burning, and a summary of fire effects data.

KEYWORDS: Great Plains; shortgrass; mixed grass; tallgrass; prescribed burning; prairie; fire ecology; fire effects

Wright, Henry A., and Arthur W. Bailey.
1980. Fire ecology and prescribed buring in the Great Plains--a research review. USDA For. Serv. Gen. Tech. Rep. INT-77, 61 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Presents basic ecological data and summarizes current knowledge about the effect of fire on vegetation in the Great Plains. Shortgrass, mixed grass, and tallgrass prairies are discussed in the southern, central, and northern Great Plains. Describes each geographic area, its vegetation, and the effects of fire. Includes sections on fire history, beneficial effects of fire, potential impacts, management implications, prescribed burning, and a summary of fire effects data.

KEYWORDS: Great Plains; shortgrass; mixed grass; tallgrass; prescribed burning; prairie; fire ecology; fire effects

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)